A

MANUAL OF FORESTRY.

BY

WILLIAM SCHLICH, Ph. D.,

PRINCIPAL PROFESSOR OF FORESTRY AT THE ROYAL INDIAN ENGINEERING COLLEGE,
COOPER'S HILL;

LATE INSPECTOR-GENERAL OF FORESTS TO THE GOVERNMENT OF INDIA

VOLUME I.

THE UTILITY OF FORESTS,

AND

FUNDAMENTAL PRINCIPLES OF SYLVICULTURE.

LONDON:
BRADBURY, AGNEW & CO., 8, 9, 10, BOUVERIE STREET.
1889.

LONDON:
BRADBURY, AGNEW, & CO., PRINTERS, WHITEFRIARS.

PREFACE.

THE present book is the outcome of circumstances, which it is desirable to explain :—

Although Forestry has been practised for centuries in Great Britain and Ireland, this particular branch of industry did not receive much attention in the United Kingdom until questions connected with the administration of the forests in India brought it into more prominent notice. In the latter country the condition of the forests began to be discussed in the early part of the present century, the first step having, apparently, been the establishment of a timber agency on the west coast of the Peninsula. Nothing more, worth mentioning seems to have occurred until the year 1843, when Mr. Conolly, Collector of Malabar, commenced planting teak on a large scale at Nilambur. In 1847 Dr. Gibson was appointed Conservator of Forests in Bombay. In 1848, as the result of action taken by Captain Frederick Conyers Cotton, the Government approved of the appointment of Lieutenant James Michael as Forest Officer in the Anamalais. Dr. Cleghorn's name is mentioned as early as 1847 in a report on the conservation

forests in Mysore, and he was ultimately appointed Conservator of Forests in Madras in 1856.

The first attempts at forest conservancy in Burma commenced soon after Tenasserim had become British territory in 1826, but nothing lasting or substantial was done until Lord Dalhousie took up the matter and, in January 1856, appointed Dr. D. Brandis (now Sir Dietrich Brandis, K.C.I.E.), Superintendent of Forests in Pegu. After six years of exceedingly hard work in Burma, Dr. Brandis was, in 1862, placed on special duty with the Government of India, and in 1864 he was appointed to the newly created post of Inspector-General of Forests to the Government of India. He remained in this position until 1881, when he proceeded on special duty to Madras: he then went to England, and retired finally from the service in 1883.

Those who preceded Sir D. Brandis prepared the way for the subsequent measures of forest conservancy, but it is the merit of that officer to have introduced into India systematic forest management as it is now understood in that country. When Sir D. Brandis first started operations, he had great difficulty in finding properly qualified assistants. He succeeded in securing the services of a limited number of good officers who were mostly military men, but he had, at the outset, also to employ many men who were

wanting in education. Accordingly, when he proceeded on furlough to Europe in 1865, he made it his business to secure a regular supply of trained forest officers. Under the arrangements made by him in 1866, a number of selected young Englishmen were sent annually for a term of two years and eight months to the Continent to study Forestry, half of them going to France, and the rest to Germany. Those of the students, who passed the prescribed examination at the close of their studies, were appointed to the Indian Forest Department as Assistant Conservators. The arrangements worked well at first, but gradually difficulties arose, in consequence of which the students were withdrawn from Germany in 1876, the whole number being concentrated at Nancy under the control of a special English officer.

About the year 1881 complaints were received as to the progress of the students at Nancy, and this led to the proposal for establishing a forest school in England, where the candidates for the Indian Forest Service might be trained. Colonel Pearson was foremost amongst those who supported this scheme. After a lengthy discussion Her Majesty's Secretary of State for India decided to start such a school in connection with the Royal Indian Engineering College at Coopers Hill, and I was deputed in 1885

to organize the new branch of that establishment. My instructions went, however, further: they included the drawing up of Handbooks on Forestry. After upwards of twenty years' administrative work I found myself suddenly called upon to instruct in Forestry and to write Handbooks on the subject —a task which, I need hardly say, was beset by great difficulties. Although I had to some extent kept up with the progress of science while in India, I had now to commence earnest study in various directions. During the vacations I visited numerous forests in England, Scotland, Ireland, Germany, Austria, France, and Switzerland. Thus several years passed before I could venture to begin writing the desired books. That task I have now commenced, and, if I am spared, I hope by degrees to deal with Sylviculture, the Preparation of Forest Working Plans, Forest Protection, Forest Utilization, and Forest Finance. On all these matters I have collected notes, but the business of preparing them for the press will be the work of years.

In order to make at once available those parts which are ready, I have decided to bring out the work in a series of small volumes. Although the ultimate arrangement of the Manual may undergo some changes as the work proceeds, my present intention is to divide it into the following parts:

Parts I. and II. are contained in this volume. Part III. will, I hope, appear early in 1890. Each volume can be purchased separately.

The information given above shows that I may fairly claim the indulgence of the reader. I do not pretend to have introduced into the work any special originality, but I have tried to arrange the matter as conveniently as possible, and to express myself as concisely as is compatible with clearness and completeness. The reader must judge for himself in how far I have succeeded in my task.

In conclusion, I desire to express my best thanks to my old Indian friends, Messrs. J. C. McDonell and W. R. Fisher, for their assistance in passing this volume through the press.

W. SCHLICH.

COOPER'S HILL,
12th March, 1889.

TABLE OF CONTENTS.

PART I.

THE UTILITY OF FORESTS.

PART II.

FUNDAMENTAL PRINCIPLES OF SYLVICULTURE.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

A

MANUAL OF FORESTRY.

INTRODUCTION.

The greater part of the dry land of the earth was, at one time or another, covered with forest, which consisted of a variety of trees and shrubs grouped according to the climate and soil of the several countries. When the old trees reached their limit of life they disappeared, and others took their place. The conditions for an uninterrupted regeneration of the forests were favourable, and the result was vigorous production by the creative power of the soil and climate. Then came man and interfered, not at once, but by slow degrees, until in the more civilized countries of the earth the area under forest was considerably reduced. But more than this: the creative power of the soil in the remaining forest lands had, through injudicious and careless treatment, become more or less impaired. Steps had then to be taken to arrest a further reduction of area, in many cases the forest had to be re-planted and the original creative power re-established; thus a task presented itself which Forestry had to undertake.

What is now understood by that term did not spring into existence all at once, but was built up gradually, as necessity in various directions arose.

As long as forests occupied considerable areas, their produce was considered the free gift of nature, like air and water; man took it, used it, and even destroyed it, without let or hindrance. Hence *Forest Utilization* is the oldest branch of Forestry.

With the gradual increase of population, more land was required for the production of field crops, and this was taken from the forest area; reckless cutting and burning consumed more forest, until a time came, when it appeared doubtful, whether the natural woodlands could continue to yield the required produce for any length of time, if treated in the manner so far customary. This caused proprietary ideas to be developed; people claimed the ownership of certain forest lands, proceeded to protect them against outsiders, and thus the first signs appeared of that branch of Forestry which is called "*Forest Protection.*" The protection, originally designed against man only, extended gradually to measures which had for their object the preservation of forests from injurious attacks by animals esp. insects, noxious plants in particular fungi, natural phenomena and other calamities.

By degrees it was found that mere protection was not sufficient, and that steps must be taken to enforce a more judicious treatment, and to limit the cuttings to what the forest was capable of producing; in other words, to determine the annual, or periodical, production, and to regulate the yield accordingly. Thus that branch which is called "*Preparation of Forest Working Plans*" sprang into existence.

Something more was, however, required. With increasing demand, it became evident that the ordinary natural regeneration could not keep pace with the rate at which the mature trees were removed. It became necessary to assist regeneration by artificial means, either by arranging the cuttings so as to favour and assist natural regeneration, or by artificial sowing and planting. Moreover, the young trees required special tending, in order to produce the most useful description of timber. In this way a fourth branch of Forestry was developed, which is called "*Sylviculture.*"

As time went by, forests rose in value; they became articles of exchange or sale, and it was found necessary to devise a system for readily ascertaining their value. This produced another branch, which is called "*Forest Valuation*" or "*Forest Finance.*"

Originally, the protection which the owner of a forest could give to it was sufficient to guard it against mischief and interference. Subsequently this proved no longer sufficient, and the owner appealed to the State for help. It was also found that certain forest lands were of special importance to the community as a whole, either on account of their produce, or for climatic reasons, or on account of the protection which they yielded to adjoining lands. For all these objects the State had to pass certain laws, which are known under the denomination of *Forest Laws and Forest Regulations.*

With the development of Political Economy, the forest question naturally was drawn within its province. It was asked, whether and in how far forests need be maintained in a country, whether the State as such should hold the forest lands, or whether the main-

tenance of forests might be left to private enterprise, and thus a further branch, called *Forest Policy* was created.

The task then, with which Forestry has to deal, is one of considerable extent; it may be shortly defined as follows:—

"To ascertain the principles according to which forests "shall be managed (Forest Science), and to apply these "principles to the treatment of forests (Practical "Forestry)."

The measures at first adopted in Forestry have, with the advance of other branches of learning, been considerably elaborated. By degrees the teachings of general science have been brought to bear upon the subject, so that at the present day a fully competent Forest Expert must be acquainted with many branches of what may be called, from this point of view, Auxiliary Sciences. Amongst these may be mentioned

Pure and Applied Mathematics.
Surveying.
Elements of General Law.
Political Economy.
Physics, including Climatology.
Chemistry, Inorganic and Organic, including a knowledge of Soils.
Mineralogy and Geology.
Zoology, esp. Entomology.
Botany.

Of these, Botany is the most important branch, and its study should extend over Vegetable Biology, Organography, Anatomy, Systematic Botany, Physiology, and Pathology.

The present object is to place before the reader an

account of the more important branches of Forestry. Before proceeding with that task, it is necessary to explain a few terms which are used in the following pages.

The term "*Forest*" has been used above. It is by no means easy to give a concise definition of what is understood under forest. In fact, various authors have given widely differing definitions, and of these the following may be here mentioned:—

First definition.—"A forest is an area which contains "wild growing trees."

At the same time many areas which are now considered forests, were artificially created, and sowing and planting may be going on in them at the present day.

Second definition.—"A forest is an area which has "been set aside principally for the production of "wood (timber and fire-wood), and which, for the "greater part at any rate, is covered with trees."

In connection with this definition it may be noted that many areas are practically classed as forests, which do not contain trees, while others, like avenues, bear trees and produce wood, although they cannot be classed as forests.

Third definition.—"A forest is a piece of land which "is subject to special forest laws and regulations."

This definition will hold good in many cases, but not in all. The Indian Legislature, when preparing a Forest Law, found it so difficult to construct a correct definition of forest, that it had to drop the subject, providing merely "that the Government may declare "certain lands to be forests."

Fourth definition.—In England a forest is frequently understood to be an area which is stocked with deer.

These illustrations will suffice to show, how difficult it is to draw up a general definition which suits all cases. In a general way forest may be described as "an area, "which is for the most part set aside for the production "of timber and other forest produce, or which is expected "to exercise certain climatic effects or to protect the "locality against injurious influences; such areas are fre-"quently subject to special forest laws and regulations."

Matters become easier when turning to the term *Wood*:—

"Under a Wood, or Woodland (Plantation) is under-"stood an area of defined dimensions, which is stocked "with trees or shrubs, and managed for the production "of timber, fire-wood, and such other produce which "ordinarily accompanies the rearing of trees."

Every "wood" is therefore a "forest," but not every forest is a wood.

The difference between a tree and a shrub is not always easy to define. For sylvicultural requirements the following definitions will suffice:—

Tree means a woody plant, which, from natural tendency, divides into two or more main branches at some distance from the ground.

Shrub means a woody plant, which, from natural tendency, divides into two or more main branches at or near the ground.

A tree may usefully be divided into three parts, the stool, the bole, and the crown:—

Stool means that part which remains in the ground after a tree has been felled close to the ground; it comprises the whole of the root system and the lower end of the stem up to the point where it emerges from the ground or a short distance (generally a few inches) above the surface.

Bole means the stem, or trunk, of the tree from the ground to the point where it divides into a series of main branches. That part (the lower) of the bole, which is free of any branches, is called the *Clear Bole.* In many cases bole and clear bole are identical.

Crown means the whole system of branches. In some cases, where side branches have been developed below the upper end of the bole, the crown and bole overlap each other.

A tree or shrub may start as a seedling, stoolshoot, sucker, or layer :—

Seedling means a tree or shrub which has sprung up from seed.

Stoolshoot means a shoot which has sprung up from the stool of a tree or shrub previously cut down.

Sucker, or Rootsucker, means a shoot which has sprung up from a root.

Layer means an undetached branch, which has been bent down, partly buried in the soil, and which has developed roots of its own; it may subsequently be severed from the mother tree and develop into an independent tree.

With regard to the age of trees and woods, the following stages may be distinguished, when the trees have emerged from that of seedlings :—

Thicket means a dense crop of young trees from the time when the branches commence interlacing until the time when the lower ones begin to die and fall; a thicket is composed of *Saplings*.

Pole forest means a crop of trees from the time when the lower branches commence falling (the bole thus clearing itself), until towards the end of the principal height growth; it consists of *Poles*.

Tree forest means a crop of trees of which the principal height growth has ceased; it consists of *Trees*, or *Formed Trees*. Towards the end of this stage it is called a *Mature Forest or Wood*.

A further distinction must be made, in respect of the persistency of the leaves, between evergreen and deciduous trees:—

Evergreen Tree means a tree, the leaves of which persist for not less than one year, so that it is never without leaves.

Deciduous Tree means a tree which is leafless for some time during each year.

Woods may be classified as follows:—

Pure Wood (or Forest) means a wood which consists of one species only.

Mixed Wood (or Forest) means a wood which consists of two or more species intermixed; the mixture can be arranged according to single trees or according to groups.

Again:—

Crowded Wood, or dense wood, means a wood which is completely stocked, so that the crowns of the trees interlace and form an uninterrupted leaf canopy, which thoroughly shelters the ground.

Thin Wood, or open wood, means a wood in which the crowns of the trees do not interlace, but form an interrupted leaf canopy, which only partially shelters the ground. A thin wood may be regularly or irregularly stocked.

For the sake of convenience the produce, which a forest yields, is divided into principal or major, and into minor produce:—

Principal or Major Produce means timber and firewood.

Minor Produce means all forest produce except timber and firewood.

Increment means the material produced on a tree, or a given area, in a certain time; *annual increment* means the material produced in one year.

Growing Stock means the material actually standing on a given area at a certain time; it consists of an accumulation of annual increments from the creation of the wood up to a given time.

Rotation means the time which elapses between the creation of a crop of trees and its final removal.

Final Yield means the material obtained by the removal of the final crop, whether the removal is effected by one or by several successive cuttings.

Intermediate Yield means the material obtained by intermediate cuttings, or thinnings.

The three principal sylvicultural systems, or methods of treatment, are represented by high forest, coppice forest, and coppice with standards:—

Seedling or High Forest.—The trees have sprung up from seed; they are permitted to grow up until they have reached the desired size, when they are cut over,

and a new crop is started consisting again of seedlings; ordinarily the cutting over does not take place until after the end of the pole stage.

Coppice Forest, or Copse.—The trees consist of stool shoots or root suckers, which are cut over periodically, either close to the ground or at some distance from it, every succeeding crop being created in the same way.

Coppice with Standards, or Stored Coppice.—A combination of the above two systems: the forest consists of an overwood and an underwood; the latter is a coppice which is periodically cut over, the stools providing each time a fresh crop; the overwood consists of seedling trees, and occasionally of vigorous stool shoots, which are allowed to reach at least twice the age of the underwood, and are called the Standards or Stores.

Quality of Locality means the yield capacity of a piece of land according to the nature of the soil and the climate to which it is subject.

These definitions will suffice for the present; all further terms will be explained as occasion requires.

PART I.

THE UTILITY OF FORESTS.

THE UTILITY OF FORESTS.

Forests are, in the economy of man and of nature, of direct and indirect value; the former chiefly through their produce, and the latter through the influence which they exercise upon climate, the regulation of moisture, the stability of the soil, the healthiness of a country and allied subjects. The effects of forests may be looked at from the point of view of the owner, or from that of the State. The owner considers, in the first place, the benefits which he personally derives from his forests; the State appreciates the effects which they have upon the country and the nation as a whole; hence, in the majority of cases, the owner is concerned chiefly with the direct effects, and the State with the indirect effects, or with both.

Each class of effects must be considered separately.

Section I.—Direct Utility of Forests.

The important direct effects of forests are due to the produce which they yield, the capital which they represent, and the work which they provide. The subject may be therefore divided in the following manner:—

1. *Principal Produce, or Wood.*

Wood is used as *timber* in construction, ship-building,

machinery, industries, agriculture, for tools, furniture, etc., and as *fuel* for domestic and industrial firing. The quantity of wood required in a country depends on various considerations, which will be dealt with further on. In modern times iron and other materials have to a considerable extent replaced timber, while coal, lignite, and peat compete with firewood; nevertheless, wood is still indispensable and likely to remain so. The more general introduction of substitutes for firewood has, however, drawn increased attention to the production of timber in preference to firewood. For instance, of the total produce of the Saxon State forests, only 35 per cent. were classified as timber in 1850, but the proportion had risen to 75 per cent. in 1880. Similarly, in Bavaria it rose from 16 per cent. in 1850 to 33 per cent. in 1880.* At the same time new demands for the consumption of wood have sprung up, such as the preparation of wood-pulp for the manufacture of paper. It is estimated that the annual consumption of wood in this industry amounts in Germany alone to upwards of 40,000,000 cubic feet. Similarly aspen firewood is now cut up for matches; beech, formerly the staple firewood, is used for furniture, floors, packing cases, pavements, etc.

A part of the firewood is converted into charcoal or into ashes. Considerable quantities of the former are still used in domestic firing, iron smelting, where a raw material of special excellence is required, in the manufacture of gunpowder, and for a variety of other purposes. Ashes are used for the manufacture of Potash or as manure.

* R. Weber in Lorey's "Handbuch der Forstwissenschaft, 1888."

2. *Minor Forest Produce.*

As all produce, which is not timber or firewood, is included under minor forest produce, it will easily be understood, that the term comprises a great variety of articles, amongst which may be mentioned: bark, especially for tanning, turpentine, resin, caoutchouc, gutta percha, catechu and numerous other dye-stuffs, leaves, flowers, fruits, seeds, fibres, grass, moss, peat, bamboos, canes, shellac, honey, wax and many others. Several of these materials play an important part in small farming, especially in poor countries, while others furnish the raw material for extensive industries. In order to illustrate the latter point, it may be mentioned that Great Britain and Ireland import such articles of an estimated value of £8,000,000 a year.

3. *Forests as Objects of Industry.*

Forests occupy a certain portion of the earth's surface; hence forestry forms part of agriculture in its widest sense. They are important objects of industry, representing a large amount of capital and they require labour in various ways, though at a rate different from those of other branches of agriculture.

a. The Capital of Forestry.

The capital employed in Forestry consists principally of the soil and the growing stock of wood. When the working is of an intermittent nature, the amount of capital fluctuates from time to time; when the working is so arranged

that an equal annual return is secured, the capital remains of the same amount and consists of the soil plus the permanently present growing stock.

The soil is called the fixed, and the growing stock the movable or shifting capital of Forestry. The proportion of the one to the other depends chiefly on the method of treatment. In forests treated as coppice woods, the fixed may be greater than the movable capital, but in high forests, where the object is to produce timber of some size, the shifting capital is generally of considerably greater value than the soil. An example will illustrate this :—Assuming that an area of 100 acres is treated as a Scotch Pine timber forest, under a rotation of 100 years, with the object of obtaining an annually equal return; in that case one acre must be stocked with 1 year old seedlings, another with 2 years' old seedlings, another with 3 years' old young trees, and so on to the last acre, which would be stocked with trees 100 years old. Every year the oldest wood, 100 years old, is cut over and the area at once re-stocked. Immediately after the cutting 99 acres remain stocked with trees ranging in age from 1 year to 99 years old, and this is called the *normal growing stock.* Without the presence in the forest of this series of age gradations, it would be impossible to obtain a regular annual yield of trees 100 years old.

The subjoined table gives the capital invested in a forest worked upon the principle of a sustained annual yield. The data for the growing stock are taken from the Yield Tables* for the Scotch Pine, by W. Weise,

* W. H. Allen & Co, Waterloo Place, Pall Mall, London, 1888, price 1s.

converted into English measures and arranged by the author. In calculating the value of the growing stock it has been assumed that, faggots would not yield any money return and the timber, including all pieces of 3 inches diameter and upwards at the thin end, would realize 2 pence per cubic foot under a rotation of 30 years, gradually rising to 5 pence per cubic foot under a rotation of 120 years. Soil adapted for the growth of Scotch Pine is generally light, and the value of such land of the I. or best quality cannot, on an average, be estimated at more than £25 per acre, while land of the III. or middling quality, may be estimated at £12 an acre, and land of the V. or lowest quality at £4, though land of the latter quality is frequently not worth more than a few shillings per acre:

Length of Rotation in Years.	Capital Invested in Forestry—Pounds Sterling per Acre								
	I. Quality, best.			III. Quality, middling.			V. Quality, lowest.*		
	Land	Growing Stock.	Total	Land	Growing Stock.	Total	Land.	Growing Stock.	Total
30	25	8	33	12	2	14	4	1	5
40	25	17	42	12	7	19	4	3	7
50	25	26	51	12	12	24	4	5	9
60	25	35	60	12	17	29	4	8	12
70	25	45	70	12	22	34	4	11	15
80	25	56	81	12	28	40	4	15	19
90	25	68	93	12	35	47	4	20	24
100	25	80	105	12	42	54			
110	25	93	118	12	50	62			
120	25	106	131	12	58	70			

This table shows:—

(1.) That the capital increases with the length of the rotation.

* No data are available for rotations of more than 90 years, in the case of the V. quality.

(2.) That the value of the growing stock is at first smaller than the value of the land, equal to it under a rotation of from 40 to 50 years, and greater after that period. Under a rotation of 90 years, for instance, the proportion is as follows:—

	Growing Stock.		Land.
For the I. quality	2·7	:	1.
„ III. „	2·0	:	1.
„ V. „	5	:	1.

(3.) That the capital invested in timber forests is considerably greater than that of the land only.

The next table exhibits the yield which may be expected from Scotch Pine forests growing on lands of the I., III., and V. quality. The data have been taken from the above-mentioned Yield Tables, and are based on the same prices as before. The yield represents the average return from final clearings and all thinnings, calculated for one acre per annum:—

Length of Rotation, in Years.	Total Yield (Final and Intermediate Cuttings) of Scotch Pine Woods, per Acre and Year.					
	I. Quality.		III. Quality.		V. Quality.	
	In cubic feet.	In shillings.	In cubic feet.	In shillings.	In cubic feet.	In shillings.
30	87	16	29	5	12	2
40	120	23	58	11	21	5
50	132	28	69	14	32	7
60	137	31	74	17	36	8
70	137	34	76	19	38	9
80	135	37	76	21	38	10
90	132	40	75	22	36	11
100	129	43	73	24		
110	124	46	70	26		
120	118	49	67	28		

By comparing now the returns with the capital, the rate of interest at which the latter is invested has been obtained and recorded in the following table, allowing 2 shillings all round per acre and year for current expenses:—

Length of Rotation, in Years.	Rate of Interest on the Invested Capital, in per cent.		
	I. Quality.	III. Quality.	V. Quality.
30	2	1·07	0
40	2·50	2·37	2·14
50	2·55	2·50	2 78
60	2·42	2·59	2·50
70	2·29	2 50	2·33
80	2·16	2·37	2·11
90	2 04	2 13	1·87
100	1·95	2·04	
110	1·86	1·94	
120	1·80	1·86	

This table shows,—

(1.) That the rate of interest obtained from the invested capital culminates under a rotation of fifty to sixty years according to the quality of the locality.

(2.) The higher the rotation beyond the culminating point, the lower the rate of interest.

(3.) Only in one case does the rate of interest exceed that obtainable from British Consols, namely on land of the V. quality, and then the excess is very slight; for the I. and III. qualities the maximum interest is about 2½ per cent.

The data upon which these calculations have been based are not absolutely correct, but they are as near the actual facts as can be ascertained. The value of the faggots, it will be remembered, has been omitted, because in many parts of England they are almost unsaleable, and at the outside they bring little over and

above the cost of cutting and preparing them. On the whole then, on financial grounds only, the conclusion seems justified that all land which can be let for the raising of field crops, for shooting or other purposes, at a rental equal to, or upwards of, 2½ per cent. of the capital value of the land, had better be so let. On the other hand, land which would realize a rental of less than 2½ per cent. of its value, may with advantage be planted with Scotch Pine, or other similarly remunerative trees. Land of the latter class may be designated as *absolute forest land.*

Apart from the purely financial aspect, there are other considerations which influence the investment, or otherwise, of capital in forestry. Of these the following may be mentioned:—

(1.) As a rule, forests do not require to be artificially manured, because trees take from the soil much smaller quantities of mineral substances than field crops. According to Ebermayer* an average forest crop, wood and leaves, requires annually about 54 per cent. of the mineral substances necessary for an average field crop. Of that quantity 46 per cent. are stored in the leaves, and 8 per cent. in the wood. It follows that, if the leaves are left in the forest, a crop of trees takes from the soil only one-twelfth the quantity of mineral substances which a field crop takes in each year; in other words, almost any soil can produce timber trees without being artificially manured, especially as the annual fall of leaves and mosses growing in the shade of the trees produce a thick layer of mould, or humus, which secures

* "Physiologische Chemie der Pflanzen," first volume, Berlin, Julius Springer, 1882.

excellent physical conditions in the soil, rendering artificial working unnecessary. As a natural consequence, the better classes of soil are generally allotted to the production of field crops, and the inferior soils to forests.

(2.) The weather, natural phenomena, animals, and men, are sources of danger to the produce of the land. In the case of field crops only the produce of one or two years at a time is exposed to such dangers, but in forestry the whole of the growing stock, or an accumulation of many years' produce, is constantly liable to be affected; on the other hand, a forest crop is, as a rule, less susceptible to damage than the more tender field crops. The greatest dangers which threaten the growing stock are those from fire, insects, and storms. A fire may destroy the whole of the growing stock, especially in coniferous forests; insects do often considerable damage by killing or injuring the trees, while storms may uproot at one time such large numbers of trees that the material becomes almost unsaleable, apart from the fact that young woods may be seriously injured, and the systematic management deranged for a considerable period.

(3.) Mistakes made in the cultivation of field crops can generally be rectified after the lapse of one year, while in forestry often long periods pass before this is practicable. If, for instance, the forester selects a wrong species for planting, he will probably not find out his mistake until many years afterwards, as most indigenous species do almost equally well on ordinary soil for a series of years; those unsuited to a certain locality will in most cases only commence to fall off in growth

some twenty or thirty years after planting. It follows that greater care and skill is required in forestry than in the cultivation of field crops so as to avoid initial mistakes.

(4.) Forest produce is a bulky article which does not bear transport, especially overland, to the same extent as the better classes of field crops. Hence the produce of forests must be consumed within a limited radius of the spot where it has been produced, unless water carriage is available.

(5.) The danger of trenching on capital is much greater in forestry than in other branches of agriculture. A farmer may to some extent reduce the value of his land by over cropping and under manuring, but this can easily be detected and rectified. In forestry the more valuable part of the capital consists of the growing stock, that is to say, material of the same class as that of which the legitimate annual return consists; hence an unscrupulous or ignorant forester can easily consume the capital, or at any rate a good portion of it, in the shape of annual income, without being detected or even becoming himself aware of the fact. In this respect, again, forestry requires greater skill and care than other branches of agriculture.

(6.) Forests, more than other lands, are burdened with rights [or servitudes] and privileges belonging to third persons. The right of property is either complete or limited. In the former case the owner can do with the property what he pleases, subject to the general laws of the country; in the latter case his power over the property is limited by rights of third persons. Such rights may be that, the third person can take produce from the forest, or use it in certain other

ways; as, for instance, for grazing cattle, or for sport. A forest right, or servitude, may be attached to a person, or to a piece of property such as a house, a piece of land, etc. In the former case it becomes generally extinct with the death of the person; in the latter it goes with the property from one legal owner to another. As a general rule, servitudes interfere much with the management and usefulness of the property. Though in many cases unavoidable, they are injurious when looked at from the view of political economy; in most countries they are peculiar to forest property.

(7.) Finally, money cannot be borrowed on forest property to its full value. Generally only the land offers absolute security, while the growing stock is not only exposed to special dangers, but can also be considerably reduced by an ignorant or unscrupulous manager without much risk of discovery. For the same reason forests are not fit objects for letting.

b. Labour required in Forestry.

Forests require labour in a great variety of ways, which may be brought under the following three headings:—

(1.) General administration, creation, tending, harvesting, etc., or work done in the forests.

(2.) Transport of produce.

(3.) Industries which depend on forests for their prime material.

(1.) *General Administration.*—The quantity of labour required in the forests differs considerably according to circumstances, the value of the produce, and the conse-

quent degree of minuteness of the system of management. Great difficulty is experienced in obtaining accurate statistics on this point, but five days' work annually for every acre of land under forest may be accepted as an approximate estimate all round. From the available data it has been calculated that in the forests of Germany about £8,000,000 are paid annually for administration, creation, preservation, road making, cutting of wood and collection of minor forest produce, on which about 200,000 families exist, or about 1,000,000 people. This estimate refers to forests which are already in existence, and in which fencing is done only in very rare instances. When new forests are created, additional labour is required at the outset. Nevertheless it is beyond doubt, that forests require considerably less labour than land under field crops.

(2.) *Transport of Produce.*—Owing to the bulky nature of forest produce its transport forms a business of considerable magnitude. Timber and firewood are carried by water, whenever practicable, but also extensively overland. Under this head a sum of at least £4,000,000 is paid annually in Germany.

(3.) *Forest Industries.*—The labour which is required to work up the raw material yielded by forests is of a much greater extent than that employed in managing the forests and in transport. There are the workmen employed in saw mills, building, ship-building, carpentry, coach building, engineering, turning, carving, paper pulp manufacture, match making, the manufacture of cases and boxes, round and square, from the largest packing case to the smallest toy box, frames of sieves, drum and cask hoops, wooden wire

for table covers, blinds, pencils, wooden nails, instruments, tools, plates, shovels, spoons, shoes, lasts, saddle-trees, brushes, harrows, gun-stocks, toys of thousands of patterns, and endless other branches of industry, some of which can only exist in and around extensive forests. The wages earned under this head amount in Germany to something like £30,000,000 a year, maintaining about 600,000 families, or 3,000,000 people.

Taking now the three heads of labour together, it has been estimated that something like 12 per cent. of the population of Germany is employed in forest work, transport of forest produce, and the working up of the raw material yielded by the forests.

An important feature of the work connected with forests and their produce is, that a great part of it can be made to fit in with the requirements of agriculture; that is to say, it can be done when field crops do not require attention. Hence forest work offers an excellent opportunity to the rural labourer or small farmer of earning some money when he has nothing else to do, and when he would probably sit idle, if no forest work were obtainable.

Section II.—Indirect Utility of Forests.

A piece of land which is bare of vegetation, is, throughout the year, exposed to the full effects of the sun and air currents, and the climatic conditions which are produced by these agencies. If, on the other hand, a piece of land is covered with a growth of plants, and especially with a dense crop of forest vegetation, it enjoys the benefit of certain agencies, which modify the

effect of sun and wind on the soil and the adjoining layers of air. These modifying agencies may be shortly enumerated as follows:—

(1.) The crowns of a full crop of trees provide a more or less dense roof at a certain distance from the ground, which intercepts the rays of the sun, and the falling rain, obstructs the movement of air currents, and reduces radiation of heat during the night.

(2.) The leaves, flowers, and fruits, augmented by certain plants which grow only in the shade of trees, form a layer of mould, or humus, which protects the soil against changes of temperature, and greatly influences the movement of water and air in the soil.

(3.) The roots of the trees penetrate into the soil in all directions and bind it together.

The effects of these agencies have been observed and recorded from ancient times down to the present, and hundreds of pages could be filled with the record of instances in which forest vegetation has affected, or has been believed to have affected, the climate, the rainfall, the regulation of moisture, the stability of the soil, the healthiness of countries and allied matters; if quantity of evidence alone were wanted, the case might be considered as "proven." In all such cases, however, two or more agencies were at work at the same time, and the observations were not always sufficiently accurate and direct to decide in how far the produced effect was due to the one or the other cause. The consequence naturally was exaggerated confidence and belief on the part of some, and doubt and unbelief on the part of others. This led in more modern times

to the commencement of accurate observations, first by Becquerel in France, and then by Nördlinger and Krutzsch in Germany, who recorded the effects of forests upon temperature and rainfall at stations situated in, or in the vicinity of, forests. A thoroughly practical and conclusive method was, however, not introduced until the year 1867, when Professor Dr. E. Ebermeyer started so-called parallel or double stations, one being situated inside a fully stocked forest, and the other at some distance from its external boundary in the adjoining open country, all other conditions, such as elevation, soil, etc., being as near as possible the same in both cases. Ebermeyer started seven double stations of this kind in various parts of Bavaria. Switzerland soon followed with three double stations in the Canton Bern; then Austria, Italy, Prussia, Alsace-Lorraine, Thüringia, Brunswick, Würtemberg, France, and others. About five years ago similar double stations were started in India (Dehra Dun, Berar, Ajmere). The result has been a rich crop of reliable observations, and although many questions await as yet a final solution, much has been learned and established, which it is proposed to indicate in the following pages. The results of the Bavarian observations were published by Dr. E. Ebermeyer in his excellent book, "Die physicalischen Einwirkungen des Waldes auf Luft und Boden," and Prof. Dr. R. Weber has quite lately brought together the more important results of all European observations in his Introduction to the "Handbuch der Forstwissenschaft," edited by Dr. T. Lorey, published in 1888. These two works have been specially utilized in the following remarks.

Before recording the results of the observations, it is

desirable to show that the variety of conditions in respect of locality and the nature of woods is considerable.

The following is a short description of the stations:—

Prussia: Sixteen double stations in all, situated in various parts of the monarchy, and in Alsace-Lorraine.

Elevation above the sea: ranging from 10 to 3,050 feet.

Distance of inside station from edge of forest: ranging from 328 to 5,248 feet.

Distance of outside station from edge of forest: ranging from 262 to 4,167 feet.

Character of woods: 6 Beech, 5 Spruce, 4 Scotch Pine woods, 1 Lüneburger Heide.

Age of woods: ranging from 20 to 110 years.

Bavaria: Six double stations.

Altitude: ranging from 1,066 to 2,956 feet.

Distance of outside station from edge of forest: ranging from 656 to 5,905 feet.

Character of woods: 2 Beech, 1 Beech and Oak, 1 Spruce, 1 Spruce and Silver Fir, 1 Scotch Pine wood.

Age of woods: ranging from 36 to 60 years.

Würtemberg: One station.

Altitude = 2,493 feet.

Distance of outside station from edge of forest = 2,297 feet.

Character of wood: Spruce wood.

Age of wood = 50 years.

Switzerland: Three stations.

Altitude: ranging from 1,476 to 2,625 feet.

Character of woods: 1 Beech, 1 Spruce, and 1 Larch wood.

Age of woods: varying from 40 to 60 years.

France: Three stations.

Elevation: ranging from 328 to 787 feet.

Distance of outside station from edge of forest: ranging from 492 to 1,312 feet.

Character of woods: 1 Beech and Oak, 1 Oak and Hornbeam, and 1 Scotch Pine wood.

Age of woods: varying from 25 to 65 years.

In all cases fully stocked areas were selected. The observations were made at fixed hours:—

(a) In the crowns of the trees (Germany only).

(b) At five feet (approximately) from the ground, inside and outside the forest.

(c) At various depths in the soil down to four feet.

(d) Measurement of the temperature of the trunks of the trees (in some cases only).

Observations extending over the following periods are available:—

Prussian stations, from 4 to 11 years.

Bavarian and Würtembergian stations, 1 year only.

Swiss stations, 12 years.

French stations, from 1 to 8 years.

From the Indian stations sufficient data are not as yet available to be of use on the present occasion.

In the following paragraphs:—

Spring	comprises	March, April, and May.
Summer	,,	June, July, and August.
Autumn	,,	September, October, and November.
Winter	,,	December, January, and February.

The subject of the indirect effects of forests will be dealt with under the following headings :—

(1.) Effect of forests on the temperature of the air and soil.

(2.) Effect of forests on the moisture of the air and the movement of water in nature.

(3.) Mechanical effect of forests.

(4.) Hygienic effect of forests.

(5.) Æsthetic effect of forests.

1. *Effect of Forests on the Temperature of the Air and Soil.*

a. Temperature of the Air.

The observations made at the twenty-nine double stations described above have shown that forests, on the whole, slightly reduce the mean annual temperature of the air. The general average of all stations has yielded the following results :

Decrease of mean annual temperature inside the forest, compared with the temperature at five feet from the ground in the open :—

At five feet above the ground .	= 1·04° Fahr.
In the crown of the trees . .	= ·41° ,,

The whole effect of a complete forest growth is, thus, a reduction of 1° Fahr. at five feet above the ground, and ·4° in the crowns; somewhat more than the average in mountainous countries, and somewhat less in the plains. So far it has not been possible to observe decided differences between the several species; in some cases Scotch Pine shows a greater reduction than Beech or Spruce, and in others the reverse has been noticed. On the whole it is clear that there is a slight decrease of

temperature from the region immediately above the crown towards the ground.

Of more importance than the mean annual temperature, is the mean temperature of the four seasons. Here, as in all future cases, a reduction in the forest is represented as minus (−), and an increase in the forest over the outside station as plus (+).

Season.	Reduction of Temperature inside the Forests, in Degrees Fahrenheit, as compared with the Temperature at 5 ft. above the Ground in the Open Country.	
	At 5 ft. above the Ground.	In the Crowns of the Trees.
Spring . .	−1·24	− ·59
Summer . .	−2·54	−1·48
Autumn . .	−1·13	− ·41
Winter. . .	− ·61	+ ·05
Mean of Year	−1·01	− ·41

These data show that the difference of temperature is greatest in summer, smallest in winter, and that spring and autumn stand about half-way. As to the crowns of the trees, the temperature is even slightly higher in winter than that of the air outside.

It is of interest to follow the course of temperature during the twenty-four hours of the day. The following figures give the differences calculated from the Bavarian and Würtembergian observations:—

Season.	Differences of Temperature between Forest and Open Country at 5 ft above the Ground in both cases, in Degrees Fahrenheit.			
	Minimum at Night.	8 A.M.	Maximum, Early Afternoon.	5 P.M.
Spring	+ ·81	−1·82	−3·87	−2·09
Summer . . .	+3·15	−3·42	−7·42	−3·44
Autumn . . .	+2·59	− ·99	−4·00	−1·06
Winter . . .	+ ·95	+ ·27	−1·96	− ·99
Mean of Year .	+1·87	−1·40	−3·91	−1·89

It will be observed, that the temperature in forests is higher during the night and lower during the day, than on open ground; the difference is most pronounced in summer, and next in autumn. This leads to the conclusion that forests tend to moderate the extremes of heat and cold. In order to illustrate this further, the following data are given, which show the extent of this action in July and January, ordinarily the hottest and coldest months of the year. The figures represent the averages of the Prussian observations made during ten years:—

Height at which Measured	Difference of the Absolute Maxima of Temperature in *July*, Mean of 10 Years	Difference of Absolute Minima of Temperature in January, Mean of 10 Years
At 5 feet above the ground	−5·87	+2·70

These figures show that the maximum temperature of forests, situated in a climate like that of Northern Germany, may be lowered in July by 5·87 degrees at five feet above the ground, and the lowest temperature in January may be raised by 2·70 degrees. The detailed observations of the different stations show further, that the above effect depends greatly on the geographical position, and the extent to which the localities are exposed to, or protected against, air currents. The effect differs also considerably according to species, as the following data will show:—

Species	Reduction of Highest Temperature in July	Increase of Lowest Temperature of January.
In Beech Woods . .	−8·37	+2·12
In Spruce Woods . .	−4·61	+4·28
In Scotch Pine Woods . .	−4·14	+2·12

Fully stocked Beech forests reduce the extremes of the air temperature during July almost twice

as much as Spruce or Scotch Pine woods; on the other hand during January Spruce woods moderate the extremes of cold twice as much as Beech or Scotch Pine woods. This is due to the dense foliage of Beech in summer and its leafless condition in winter: while the leaf canopy of Scotch Pine woods is always much thinner than that of Spruce woods.

It has thus been established that forests situated immediately to the north and south of the 50° northern latitude reduce the temperature of the air in their interior, which effect communicates itself to the surrounding country, owing to the continuous interchange of air between the two. The actual effect is probably somewhat greater than the above data indicate, because many of the outside stations were situated so close to the edge of the forest that their temperature was already somewhat affected by an interchange of the air. This has been illustrated by the fact, that greater differences of temperature were observed in those cases, where the outside stations were situated at a great distance from the edge of the forest. With the view of arriving at more final results on this point a commencement has been made in Austria to establish a system of so-called radial stations, that is to say, several series of points of observation which commence in the centre of a considerable block of forest, and are placed, in various directions, at fixed intervals, from the centre and gradually into the open country surrounding the forest. In this way it is hoped to ascertain to what distance the effect of forests on the temperature of the air extends into the open country.

Dr. Woeikof, Director of the Meteorological Institute

at St. Petersburg, has published several series of figures, with the view of illustrating the effect of extensive forest areas on the temperature of the surrounding country. He gives the mean temperature of July for various series of places, each series being situated as near as possible on one and the same degree of latitude, after having reduced the data to the same latitude and an elevation of 656 feet above the sea. The following figures are those given for two series:—

MEAN TEMPERATURE OF JULY REDUCED TO AN ALTITUDE OF 656' IN DEGREES FAHR.

	On the 50th degree of Northern Latitude.		On the 38th degree of Northern Latitude.
Guernsey	59·5	Lisbon	70·5
Brussels	62·6	Campo Maior	76·3
Würzburg (Main valley)	64·9	Palermo	76·5
Promenhof (N.W. Bohemia)	64·4	Athens	79·2
Prague (centre of Bohemia)	[illegible]	Smyrna	77·9
Hochwald (Moravian plateau)	63·7	Lenkoran	74·7
Trenczin	68·0	Krasnowodsk	82·0
Arvavaralja (N.W. Hungary)	61·2		
Lemberg	67·5		
Kiev	68·9		
Charkow	69·4		
Szemipalatinsk	72·7		

Dr. Woeikof points out that the temperature rises on proceeding from the Atlantic Ocean in an easterly direction to continental countries; indeed, there is a difference of 13·2 degrees between Guernsey and Szemipalatinsk, and of 11·5 degrees between Lisbon and Krasnowodsk. This on the whole steady increase of temperature is here and there interrupted, a phenomenon which he ascribes to the presence of extensive forests. He points out that on the 50th degree of latitude the first decided fall occurs at Promenhof, which has in its vicinity the extensive forests situated on both sides of the Bavaria-Bohemian frontier. Then at Hochwald

the second fall occurs, a place which is situated close to extensive forests. Further east, at Troppau, the temperature rises again, but on entering the densely wooded valleys of the Hungarian Carpathians, a third depression of temperature becomes apparent. The comparatively low temperature in eastern Gallicia, at Lemberg, is also ascribed to the presence of extensive forests; while large forests and marsh lands are found close to the north-west and north-east of Kiew. As soon as the Steppes are approached the temperature rises rapidly. As to the places situated on the 38° of latitude it is pointed out, that the temperature rises rapidly from Lisbon towards the interior until Athens is reached; at Lenkoran a decided fall is shown, ascribed to the presence of dense forests.

These and other similar data are very interesting and suggestive of certain effects on the temperature exercised by the presence of large forests; still, they should be received with caution, because it is impossible to ascertain in how far other circumstances may have produced the reductions, such as exposure to air-currents, presence of large sheets of water, swamps, &c. Thus, large marshes are found at Kiew, while Lenkoran is situated on the banks of the Caspian Sea.

b. Temperature of the Soil.

As the temperature of the soil follows the temperature of the air near the surface in its upward and downward movements, it is necessary to observe the temperature at various depths. The following is an abstract of the Swiss, Bavarian, and Würtembergian observations:—

Season	Differences of Mean Temperature of Soil between Forest and Open Ground, in Degrees Fahrenheit				
	On the Surface	At 1 foot below the surface.	At 2 feet below the surface.	At 3 feet below the surface	At 4 feet below the surface
Spring	1·15	−3·33	−3·17	−2·64	−2·13
Summer	−6·89	−6·71	−6·80	−6·81	−6·64
Autumn	2·29	−2·11	−3·02	−3·29	−3·64
Winter	·20	+ ·11	− ·01	·00	− ·20
Mean of Year	−4·14	−3·02	−3·24	−3·20	−3·17

The following conclusions may be drawn from these figures:—In the first place the mean annual temperature of the soil is nearly the same from 1 foot below the surface down to 4 feet. Next, it is evident that the mean annual temperature of forest soil is decidedly lower than that of soil in the open; in summer by nearly 7 degrees, very little in winter, while spring and autumn hold positions half way. In spring the temperature sinks from the surface down to 4 feet, and in autumn the reverse takes place.

The effect differs considerably in the case of different species. In this respect the Swiss observations, average of 12 years, have yielded the following results:—

Season.	Difference of Temperature of the Soil Inside and Outside of Forests, according to Species.		
	Spruce	Beech	Larch.
Spring . . .	−5·72	−2·17	−2·03
Summer . . .	−9·18	−6·43	−1·88
Autumn . . .	−1·10	−2·99	−2·56
Winter . . .	+ ·10	− ·16	+ ·59
Mean of Year . .	−4·81	−3·01	−2·21

The evergreen Spruce reduces the temperature of the soil considerably more than the deciduous Beech, and

still more so than the Larch. This difference is very pronounced in spring, that is to say, during the season when the trees commence the annual cycle of growth.

The above data seem to justify the following conclusions:—

(1.) The climate of forest countries is more equable than that of open countries.

(2.) The mean temperature of soil and air in forest countries is somewhat lower than that of soil and air in open countries.

(3.) The reduction of the temperature may act beneficially in hot countries, but it may be injurious in countries removed from the equator, where the temperature is already lower than is good for the ripening of field crops.

(4.) Vegetation awakens later in spring in well stocked forests, than in open ground.

(5.) As forests moderate the extremes of temperature, plants growing under the shelter of a forest crop are less liable to suffer from late and early frosts or from drought, than plants growing in the open.

2. *Effect of Forests on the Moisture of the Air and the Movement of Water in Nature.*

Air can hold only a certain maximum quantity of vapour, which increases and decreases with the temperature. When the maximum has been reached, and more vapour is introduced, a part becomes fluid. The absolute vapour in the air is measured by its tension upon a column of mercury, as represented in a barometer. The

proportion of the absolute tension to the maximum tension of vapour, which is possible at a certain temperature and pressure, is called the relative humidity of the air. Although the humidity of the air depends in the first place upon the general distribution of heat and air pressure over the large sheets of water on the earth, which govern the direction and force of the moist air currents, the vegetation of the earth must also affect the degree of humidity, chiefly because it reduces the temperature locally. That effect may be felt in the degree of humidity of the air, the amount of precipitation, the degree of evaporation, and in the feeding of springs and rivers.

a. Humidity of the Air.

The observations so far available show that forests do not affect the *absolute* humidity of the air to any appreciable extent. Those made in Bavaria yielded the following results:—

Season	Mean Absolute Vapour Tension, in Inches		
	In the Open, 5 feet above Ground.	In Forest, 5 feet above Ground	Excess in Forest
Spring	·2788	·2824	+ ·0036
Summer	·4626	·4618	− ·0008
Autumn	·2806	·2886	+ ·0080
Winter	·1820	·1918	+ ·0098
Mean of Year	·3010	·3064	+ ·0054

These figures show that the increase in forest did not reach 2 per cent. of the quantity outside. More extended observations have since shown that the difference is even smaller, and in some cases forest air has been found to contain less absolute vapour tension than open air.

It is different with the *relative* humidity of the air. As the temperature of forest air is on the whole lower

than that of open air, while the absolute humidity remains the same, it follows that the relative humidity of forest air must be greater than that of open air, more especially in summer. The following data will illustrate this:

The Bavarian observations of 1868—69 gave the subjoined results, as a general average:—

Season.	Mean Relative Humidity, in per cent of Saturation.		
	In the Open, 5 feet above Ground	In Forest, 5 feet above Ground	Excess in Forest.
Spring	74·96	80·66	+5·70
Summer	71·92	81·20	+9·28
Autumn	82·72	87·94	+5·22
Winter	84·10	89·13	+5·21
Mean of Year . .	78·45	84·81	+6·36

These observations show that the mean annual excess amounted to 6·36 per cent. There was, however, a decided difference according to the altitude of the stations. While the excess amounted to only 3·14 per cent. at 1,066 feet above the sea, it was as much as 8·79 per cent. at 2,956 feet elevation. Further differences have been recorded according to the species, as the following data will show, representing the averages of the German and Swiss observations:—

Season.	Excess of Relative Humidity in Forest over the Open Country, in per cent. of Saturation.			
	Beech	Spruce	Scotch Pine	Larch.
Spring	+1·01	+6·92	+2·93	+2·83
Summer	+9·35	+8·50	+3·87	+7·85
Autumn	+1·07	+7·01	+4·24	+5·15
Winter	+1·73	+1·76	+2·70	+·31
Mean of Year . .	+4·27	+6·81	+3·42	+4·12

Evergreen dense Spruce woods produce a much greater effect than the thin crowned Scotch Pine, or the deciduous Beech and Larch. At the same time the greatest

effect is produced in Beech woods during summer, owing to the dense leaf canopy which exists in such woods at that season.

The detailed figures show, that the mean annual excess in forests ranged from 3 to 10 per cent., which explains, why dry air currents striking through forests become in a short time relatively moist, so that precipitations may be caused. At any rate there can be no doubt that the formation of dew is much greater in the vicinity of forests than on open ground away from woodlands.

b. Precipitations, or Rainfall.

The question whether, and in how far, forests affect the rainfall, is one which has been actively discussed for many years past, but so far no final decision has been possible. That forests can affect precipitations follows from the facts, that forest air is relatively moister than air in the open, and that the trees mechanically affect the movement of the air; but, on the other hand, the rainfall depends chiefly on other much more powerful agencies, in comparison with which the effect of forests is small. Numerous comparative observations have been made, but only a certain portion has so far been published, and unfortunately those which seem to indicate a decided effect of forests on the rainfall are not always very reliable. The great difficulty in comparing the results of observations at forest stations (that is to say stations situated inside a forest) with those of the ordinary meteorological stations, consists in the fact, that elevation above the sea affects the rainfall most powerfully, because air cools on rising and precipitations become more frequent with elevation.

Although further observations are necessary, before a

final conclusion can be arrived at, the following data may prove interesting:—

In the Prussian system the forest stations have shown the subjoined increase of rainfall over the average rainfall of the open country as taken from the ordinary meteorological stations:—

	Excess of Rainfall in Forest Station over that of Open Country, in per cent. of the latter Rainfall.
Between Sea level and 328 feet elevation	1·25 per cent.
,, 328 and 556 feet ,,	14·2 ,,
,, 1,969 and 2,297 feet ,,	19 ,,
,, 2,297 and 2,625 feet ,,	43 ,,

Although these figures may not represent the absolute facts of the case, they seem to indicate that in the plains forests have very little effect upon the rainfall, if any at all, but that their influence becomes considerable with increasing elevation in mountainous countries.

The results of 7 years' observations made at two stations near Nancy show a decided increase of rainfall in the forest. The stations are situated 1,247 feet above the sea, one in the middle of an extensive forest 5 miles to the west of Nancy, the other in an almost woodless country 6 miles to the north-east of Nancy. The results were as follows:—

	Increase of Rainfall in Forest over that in the Open, in per cent. of the latter.
February to April	7 per cent.
May to July	13 ,,
August to October	23 ,,
November to January	21 ,,
Mean of Year	16 ,,

that is to say, an increase of 16 per cent. in the forest station.

Other evidence tending in the same direction is available, but the Bavarian observations do not justify any direct conclusion as to any increase in the absolute rainfall due to the action of forests.

On the whole it may be said, that various physical factors act towards rendering forests excellent condensators of vapour, because they have a lower temperature, a moister air, and break the force of air currents. These properties are more evident in elevated positions than in low lands and in the vicinity of the sea, where they are swamped by other more powerful agencies. Absolute certainty in respect of these phenomena can only be obtained through further extensive observations.

There can be no doubt on one point, namely, that the presence of a forest crop prevents a considerable portion of the rainfall from reaching the ground, because it is interrupted by the crowns of the trees. The various measurements have yielded the following results:—

Stations	Quantity of Rainfall which reached the Ground in well stocked Woods, in per cent of Total Rainfall.			
	Beech Woods	Spruce Woods	Scotch Pine Woods	Larch Woods
Prussian Stations .	76	78	78	...
Bavarian Stations .	78	73	66	.
Swiss Stations . .	90	77	. .	85

The total average of the Bavarian stations shows 77 per cent. of the rainfall as having reached the ground, whereas 23 per cent. were intercepted by the crowns of the trees, and which evaporated or partly ran down the trunks of the trees.

c. Evaporation.

Owing to the lower temperature, the greater humidity of the air, and the quieter state of the atmosphere, evaporation must be considerably smaller in forests than in the open. This has been conclusively proved by direct observations. Those made in Bavaria and Prussia show the following results :—

Stations.	Quantity of Water Evaporated from a free Surface of Water, Height in Inches			Less in Forest expressed in per cent. of the total Quantity evaporated in the Open.
	In the Open.	In Forest.	Less in Forest	
Bavarian . .	23·53	8·61	–14·92	–63
Prussian . .	13·16	5·98	– 7·18	–55
Mean . .	18·34	7·29	–11·05	–60

Those data show that evaporation in the forest was only two-fifths of that in the open country.

The effect of this action is, that of the water which falls on the ground in a forest, a considerably larger proportion is secured to the soil, than in the open. That water is available to be taken up by the roots, while any balance goes to the ground water and helps to feed springs. Of considerable importance in this respect is the covering of forest soil. Dr. Ebenmayer's observations on this point, extending over 5 years, show the following results :—

	Parts.
Water evaporated from soil in the open . .	=100
Evaporation from forest soil, without leaf-mould .	= 47
" " " " with full layer of leaf-mould . .	= 22

In other words, forest soil without leaf-mould,

evaporated less than half the water evaporated in the open, while forest soil covered with a good layer of humus evaporated even less than one-fourth of that evaporated in the open.

The result of these peculiarities is, that, at any rate up to a certain elevation, the forest soil retains, after allowing for evaporation, more water, than open soil, although some 23 per cent. of the rainfall are intercepted by the crowns of the trees. In order to illustrate this the following table, taken from Dr. Weber's calculations, is inserted, as it draws the balance of rainfall over evaporation, according to elevation; it is based upon the Prussian observations:—

Altitude of Stations in Feet	Excess of Rainfall over Evaporation, in Inches.		Percentage of Rainfall which Evaporated	
	In the Open	In Forest	In the Open	In Forest
0—328	12 02	12 32	55	37
328—656	12 69	13 84	53	30
981—1312	12 20	17·65	59	25
1969—2297	36 96	30 79	22	13
2540	47·10	43 08	15	9
3050	56 77	46·31	19	11

This table shows that the balance of water retained by the soil increases rapidly with altitude, and that the evaporation in mountain forests may be reduced to about 10 per cent. of the rainfall. If it be remembered, that the moisture is most effectually preserved in forests, it will easily be understood why the mountain forests have from time immemorial been looked upon as the preservers of moisture and feeders of springs. No doubt, a certain portion of the water is again taken out of the ground by the roots of the trees and evaporated through the

leaves. The quantity thus consumed is not known at present, but it cannot be more than 12 inches, the total quantity available in plain forests, and probably it becomes less with elevation, so that a considerable balance remains available in hill forests for the feeding of springs.

3. *Mechanical Effect of Forests.*

The mechanical effect of forests makes itself chiefly felt in regard to the distribution of the rain-water, the preservation of the soil on sloping ground, the binding of moving sand, the prevention of avalanches, and the moderation of air currents.

a. Feeding of Springs and Rivers.

Most of the rainwater falling on a bare slope rushes down into the nearest watercourse in a comparatively short time, thus causing a rapid rise in the level of the stream. Only a comparatively small portion sinks into the ground, so as to become available for the feeding of springs. Of the rain falling over a forest, close on one-fourth is intercepted by the crowns of the trees, and the other three-fourths fall upon a layer of humus, which possesses a great capacity to absorb water and to retain it for a time. It has been shown, for instance, that mosses of the species Hypnum, which grow under the shade of conifers, can absorb up to 5 times their own weight of water, and peat mosses of the genus Sphagnum up to 7 times, while the leaf-mould to be found in a middle-aged well-preserved Beech wood can absorb and retain for a time a rainfall of 5 inches.

Part of the water thus absorbed penetrates into the ground and becomes available for the feeding of springs, while the rest gradually finds its way into the nearest stream. In this manner well-preserved forests must have a decided effect upon the sustained feeding of springs and the moderation of sudden floods in rivers. When, however, the humus has been saturated with water, and rain continues, the effect of forests as regards inundations must cease, because the additional water follows the laws of gravity and finds its way into the valleys. Hence the effects are of limited extent, a matter which has frequently been overlooked in discussing the subject. In order to moderate inundations to any appreciable extent, it would be necessary to keep a very large proportion of the catchment area under forest, and even such a measure would only afford protection to a limited extent.

b. Protection of the Soil.

Water rushing down a bare slope possesses a great mechanical power, by means of which it loosens the soil, and carries it down hill. In this way landslips are often caused, ravines are formed, and fertile land, situated at the foot of the ravines, may be covered with silt and rendered valueless. Frequently the *débris* collects in rivers and forms obstructions, which are followed by a diversion of the bed and erosion of fertile lands. The rate at which this process proceeds, depends on the geological origin and the formation of the surface; the less binding the soil and the looser the formation, the greater will be the damage. If, on the other hand, such

a slope is covered with a well preserved forest, the roots of the trees and the layers of humus keep together and protect the soil against the action of water; besides the crowns intercept and retain, at any rate for a time, a considerable portion of the water. On the whole, a series of obstacles are opposed to the movement of the water, which reduce its velocity and force, or at any rate divide it into numerous small channels. The beneficial effect of tree vegetation in this respect can be observed in most mountain ranges, and especially in the Alps from France to Austria. Wherever, in those parts, extensive deforestations have taken place, the consequence has been the gradual formation of a series of torrents, in all places where the surface did not consist of hard rock; the *débris* brought down has covered more and more fertile land at the base of the torrents, and this evil has grown to such an extent, that not only in France, but also in the other Alpine countries, great efforts are now made to re-afforest the denuded areas, at a great outlay. When once the evil has been created, immediate afforestation is not possible; it must be preceded by the construction of dams, dykes, walls, &c., to steady the soil until the young forest growth has had time to establish itself and once more to lay hold of the surface soil.

The importance of maintaining a complete cover of vegetation in all such cases was recognized many years ago, so that already in the middle ages so called "Protection Forests" existed, which the then existing laws protected against devastation. Although the effect here described is perhaps most complete in the case of a well-stocked forest, similar effects can be

produced by covering the soil in other ways, as for instance by a dense growth of heather, by turf, &c.

Forests protect the soil not only in the hills, but also in low lands, wherever it consists of so-called moving or shifting sand, along the sea coast as well as in the interior of countries. The action in this case is due partly to their moderating the force of the air currents and partly by keeping the soil together through their roots, by the formation of humus and the retention of moisture. In this way the Landes of France have, from a dreary waste, been converted into extensive forests intersected by cultivated fields.

c. Protection against Avalanches.

Although most avalanches in the higher hills originate above the upper limit of tree growth, there are many cases where the presence of a well-preserved forest protects towns and villages lying below them by preventing the formation of avalanches, or by stopping their forward movement and increase as long as they are as yet small. Hence many forests in the Alps are maintained as a protection against avalanches.

d. Protection against Air Currents.

Forests break or moderate the force of air currents, and in this way afford protection to lands lying beyond them against cold or dry winds. Whether such effect is beneficial or otherwise, depends on the geographical position, the local climate, and the season of the year. Woodlands afford also shelter to cattle, game, and useful

birds. Their importance in this respect should not be overlooked; forest grazing is frequently of greater value than grazing on open ground; the presence of birds, which are the great enemies of injurious insects, depends often on that of woodlands.

4. *Hygienic Effect of Forests.*

Forests, in forming a substantial part of the vegetation of the earth, are an important agency for the production of Oxygen obtained by the decomposition of Carbon Dioxide. Direct observations have also shown that forest air (like sea air) is much richer in Ozone than the air of open countries, and especially of towns. Professor Ebermayer gives the following results, the maximum content of Ozone being indicated by 10, and complete absence by 0:—

Stations.	Contents of Ozone in the Air.			
	Spring.	Summer.	Autumn.	Winter.
Average of the six Bavarian double stations situated inside and in the vicinity of forests	8·20	7·71	7·09	8·36
Aschaffenburg, town	6·81	6·24	5·35	6·04
Leipzig, town	5·42	6·93	3·65	3·37
Zwickau, town	3·23	3·11	2·21	1·81

The difference between forest countries and towns is greatest during winter, which seems to show that the contents of Ozone do not depend on the action of the leaves. It was also found that the air inside forests contained slightly less Ozone than along the edge of the woods, which may be due to the presence of large quantities of decaying matter (humus) in the forest.

If forests, then, produce Oxygen and Ozone and protect human habitations against injurious air currents, they may exercise a beneficial effect upon the healthiness of adjoining lands. Instances are not wanting where forests are said to have given protection against the germs of malaria, but there are others, where they are said to have had the opposite effect. As far as India is concerned, in some cases the medical authorities of military cantonments ordered forests to be planted, and in others to be cut down. Whether certain species, such as Eucalyptus, really possess the quality of drying up soil and thus remove swampiness, has yet to be proved.

5. *Æsthetic Effect of Forests.*

As forests increase the artistic beauty of a country, they must influence the character of the people, especially as they are favourite places of recreation. Many of the British woodlands were created, or are maintained, for their æsthetic effects.

Section III.—Summary of Conclusions.

The various ways in which forests exercise an influence in the economy of man and of nature may be summarized as follows:—

(1.) Forests supply timber, fuel and other forest produce.

(2.) They offer a convenient opportunity for the investment of capital and for enterprise.

(3.) They produce a demand for labour in their management and working, as well as in a variety of

industries which depend on forests for their raw material.

(4.) They reduce the temperature of the air and soil to a moderate extent, and render the climate more equable.

(5.) They increase the relative humidity of the air and tend to reduce evaporation.

(6.) They tend to increase the rainfall.

(7.) They help to regulate the water supply, ensure a more sustained feeding of springs, tend to reduce violent floods, and render the flow of water in rivers more continuous.

(8.) They assist in preventing land slips, avalanches, the silting up of rivers and low lands, and arrest moving sands.

(9.) They reduce the velocity of air currents, protect adjoining fields against cold or dry winds, and afford shelter to cattle, game, and useful birds.

(10.) They assist in the production of Oxygen and of Ozone.

(11.) They may under certain conditions improve the healthiness of a country, and under other conditions endanger it.

(12.) Finally they increase the artistic beauty of a country.

Whether, and in how far, these effects are produced in a particular country depends on its special conditions. As regards the *direct* effects, enumerated under 1, 2 and 3, the following considerations are of importance in deciding whether existing woodlands should be preserved, or new forests created :—

(1.) The position of the country, its communications

with other countries, and the control which it exercises over other countries.

(2.) The quantity and quality of substitutes for forest produce available in the country.

(3.) The value of land and labour, and the returns which land yields, if used for other purposes.

(4.) The density of population.

(5.) The amount of capital available for investment.

A country so situated that the importation of wood and other forest produce is comparatively easy and cheap (sea-bound, traversed by navigable rivers coming from countries which are rich in forests, or intersected by numerous railways and other means of communication), or which has control over other countries, as for instance colonies rich in forests, can dispense with extensive forests. In a country which is rich in coal, lignite, or peat, the production of firewood is of subordinate importance. Where iron or other substitutes for timber are available in sufficient quantity and at a low rate, forests are not required to the same extent, as in a country which does not enjoy such advantages. Where land under field crops yields, even if forest produce is imported, a higher interest on the invested capital than under forest, the latter would, in this respect, be undesirable. If the population of a country is very dense, and all land is required for food, forests would be out of place. Where, on the other hand, waste lands exist, which are not required or unsuited for field crops, and where the population is at the same time in want of additional work, it may be advisable to create forests so as to increase the returns from surplus lands, and to provide occupation through the

operations connected with the administration of the forests and the industries which the existence of forests tends to create.

In considering the advisability, or otherwise, of afforesting a country, with special reference to the *indirect* effects of forests, the most important points are its climate and configuration. The nearer to the equator, the more important becomes, as a rule, the forest question, and the further removed from it, the less important. While forests may in a hot country, with distinct wet and dry seasons, be absolutely necessary for the mitigation of extreme heat and dryness during certain parts of the year, and the regulation of the flow of water in springs and rivers, they may be injurious in a northern country, which is already too cold and damp. Similarly, a continental country may require forests, while a sea-bound country may be better without them, as far as climatic considerations are concerned. A mountainous country is much more in need of forests than a low lying country, on account of their beneficial action as regards landslips, avalanches, the carrying away of débris, the silting up of rivers and low lands, sudden floods, and the sustained feeding of springs. As regards the protection against strong winds and shelter to cattle and useful birds, forests act beneficially in any country.

On the whole, no general rule can be laid down showing whether forests are required in a country, or what percentage of the area should be so used. The forest question must be determined on the special circumstances of each country. By way of illustration

the areas at present under forest in a number of countries are shown in the following table:—

Countries	Area under Forest, in Acres.	Percentage of Total Area of Country under Forest	Forest Area per Head of Population, in Acres.	Distribution of Forest Area according to Ownership, in per cent of total Forest Area: State and Crown Forests.	Forests of Corporations, Endowments, etc.	Private Forests.
Servia	[illegible]	48	3·[illegible]			
Russia, in Europe	527,4[illegible]7,000	42	6·1	60*	40	
Sweden	12,3[illegible],000	42	9·1	20	80	
Austria Proper	21,161,000	33	1·1	6	94	
Hungary	22,[illegible]2,000	29	1·1	16	52	32
Germany	34,350,000	26	·8	33	19	48
Norway	18,930,000	25	9·9	12	*	88
Turkey (including Bulgaria, Bosnia and Herzegovina)	20,812,000	22	3·5	*		
Roumania	4,[illegible],000	22	·9	**	**	*
Italy	14,225,000	22†	·5	4	43	53
Switzerland	1,930,000	19	·7	4	67	29
Spain	21,3[illegible]3,000	17	1·3	82‡		18
France	20,[illegible]70,000	16	·6	11	23	66
Greece	2,023,000	16	1·2	80	*	20
Belgium	1,073,000	15§	·2		*	
Holland	554,000	7	·1	*		
Denmark	477,000	6	·2		**	
Portugal	1,100,000	5	·2			
Great Britain and Ireland	2,750,000	4	·1	*		
Total for Europe	760,821,000	31	2·3	*	*	
United States of N. America	250,000,000	17	7·0	*	*	
East India, British	140,000,000	25	·6	60*	[illegible]0*	

Considerable differences exist in respect of the data available for several of the countries. In all such cases the data which appeared most reliable, have been entered in the above table. The percentage of forest area varies from 48 to 4, and the area per head of population from 9·9 to ·1 acres. This shows that the general conditions in the various countries must make different demands in respect of afforestation. Servia, Russia,

* Approximate. † Includes olive woods.
‡ Includes probably the Corporation forests. § Others give 7 per cent.

Sweden, and Norway, may as yet have more forest than they require for their own population. On the other hand, Great Britain and Ireland, Portugal, Denmark, Holland, Belgium, and even France and Italy have a smaller forest area than is necessary to supply them with a sufficient quantity of forest produce. At the same time, they are all sea-bound countries, and consequently subject to conditions, which differ altogether from those found in continental countries; most of them are under the influence of moist sea winds, and all are favourably situated in respect of importation by sea.

Intimately connected with the area under forest in a country, is the state of ownerships. Forest owners may be grouped into the following three great classes:—

(*a.*) The State or the Crown.
(*b.*) Corporations, Endowments, etc.
(*c.*) Private persons.

Where forests are not required on account of their indirect effects, and where importation from other countries is easy and assured, the Government of a country need not, as a rule, trouble itself to maintain or acquire forests, but where the opposite conditions exist, that is to say, where forests are necessary to produce climatic and mechanical effects, and where the cost of transport over long distances becomes prohibitive, a wise administration will take measures to assure the maintenance of a certain proportion of the country under forest. This can be done, either by maintaining or constituting a certain area of State forests, or by exer-

cising a certain amount of control over Corporation and private forests. In most civilized countries, Corporation forests are subject to the control of the State, though the degree to which such control is exercised may differ. Private forests are free from control in some European States, and subject to it in others. In all such cases the State is only justified in interfering when the welfare of the general community requires it. The extent to which interference may be carried depends on the special conditions of each country, and on the proportions of the forest area belonging to the State. Thus, of the Swiss forests only 4 per cent. belong to the State, while 67 per cent. belong to Corporations, and 29 per cent. to private owners; at the same time, a large portion of the area are so-called protection forests, and in consequence Government exercises an extensive control over both Corporation and private forests. Of the German forests 33 per cent. belong to the State, 19 per cent. to Corporations, and 48 per cent. to private persons; the Corporation forests are under State control, making, with the State forests, 52 per cent. This being more than one-half of the area, the control over private forests has of late years been considerably reduced, and in some parts abolished altogether. It is worthy of notice that only 20 per cent. of the Swedish and 12 per cent. of the Norwegian forests belong to the State, while the bulk are private forests, over which little or no control is exercised by the State. Large quantities of timber are exported annually from these countries to Great Britain and other countries, and it may safely be expected, that these supplies will considerably decrease in the course of time.

APPENDIX I.

FORESTRY IN GREAT BRITAIN AND IRELAND.

1. *Indirect Effects of Forests.*

In applying the above conclusions to Great Britain and Ireland, it should be remembered, that the climate and rainfall of these islands are principally governed by their insular position, which exposes them to strong moist air currents coming direct from the sea. Compared with their effects, those of forests, even if they occupied 20 per cent. of the total area, would be found comparatively small. Again, a great portion of the waste lands in Great Britain and Ireland is covered with heath, and a considerable portion with peat mosses, which are most powerful agents in the retention of water; in this respect the addition of trees would make comparatively little difference; moreover, afforestation would, in many cases, be accompanied by the draining of the soil, which would counteract the effects of forests. Lastly, Great Britain and Ireland get as much rain as they require, and in many parts more than is good. As regards climate and rainfall an increase of the forest area is, therefore, not required.

The next point for consideration is the effect of forests on the regulation of the moisture, on floods, landslips, erosion, etc. If Great Britain and Ireland were situated in a more southern latitude, or removed from the sea,

their configuration, especially that of Scotland and Ireland, would probably make afforestation a necessity, but owing to the existing climate, the waste lands are naturally clothed with a covering, which retains water in a high degree, and binds the surface soil well together. The upper part of the hill ranges is, in many cases, bare, and there afforestation might produce some good effects, but the undertaking, even if the plantings were successful, would never pay, and it could only be justified on public grounds if the damage done by the rushing down of the rain-water was great. Damage of this kind occurs occasionally, but on the whole it is not considerable. The rock is in most parts sufficiently consistent, or at any rate covered with a sufficient growth of plants to resist any appreciable eroding action of the rain-water. On the whole, afforestation is in this respect not called for; at any rate, the question is neither urgent nor very important, so long as erosion is not artificially started by the act of man. Damage by floods occurs in some parts, but it will be cheaper to suffer the loss, or to meet it by engineering works, than by the afforestation of unpromising steep hill-sides.

The action of forests on winds and the protection which wood lands afford to cattle and useful birds deserve, however, attention. It is well known that the strong sea breezes which sweep over these islands impede, to a considerable extent, the successful prosecution of agricultural operations, more especially along the western coastlands, and any measure which would reduce this baneful effect must be beneficial. Much good could be done in this respect by a judicious distribution over the country of belts and blocks of forest.

2. *Forest Produce.*

Great Britain and Ireland are well supplied with coal and peat, and the production of firewood is of very little importance. As a matter of fact, firewood is unsaleable in many parts of the country. The question of the supply of timber and minor produce requires a more detailed notice. Although the production of iron is enormous, the imports of wood into Great Britain and Ireland are very considerable. Large quantities of minor forest produce are also imported, articles which serve as the raw material in various branches of industry.

The following information has been extracted from the Annual Statements of the Trade of the United Kingdom. It shows the average annual value of the importations of timber and other forest produce, calculated from the returns for the five years of 1883 to 1887, to have been as follows:—

	£*
Value of Minor Produce, such as tanning bark, cork, caoutchouc, cutch, myrobalans, dye-woods, gums of various kinds, gutta-percha, turpentine, pitch, tar, resin galls, wood pulp	8,000,000
Value of Imported Wood (round figures) .	15,000,000
Total Annual Import .	23,000,000

* Mr. Simmons in the "Journal of the Society of Arts," 19th December, 1884, gives the following figures for the year 1883 only:—

Value of minor produce .	14,000,000
Value of wood	18,000,000
Total .	32,000,000

The greater part of the minor produce is of such a nature, that it could not be produced in these islands. Certain articles, however, such as tanning bark, wood pulp, and to some extent turpentine, resin, pitch, and tar might be grown and manufactured in this country; the total of such articles would probably not exceed a value of £1,000,000.

As regards timber, about £3,000,000 represent the value of Teak, Mahogany, and a series of fancy woods, which could not be grown in the United Kingdom. The remaining £12,000,000 represent the value of coniferous woods, Oak, etc., which can be produced in the country. The total value of produce, which is at present imported, but which could be grown at home, thus approximately amounts to:—

		Value.
Minor produce . . .	=	£1,000,000
Timber	=	12,000,000
Total .		£13,000,000

The timber included in this valuation comprises on an average, calculated from the returns for 1883—87, 5,869,667 loads a year. It is not easy to determine the exact area which would be required for the production of that timber, but roughly speaking, it may be estimated at 6,000,000 acres; the question arises then, whether such an area is available, and if so, whether it is advisable to increase the area under forest in the United Kingdom to such an extent as to meet future requirements of timber, or whether the Colonies and other countries may be relied on to meet the demand.

According to the Agricultural Statistics for 1884—85,

the distribution of land amongst the different branches of agriculture was as follows :—

Distribution of Land.	Area in Acres.				Percentage of Total Area.			
	England and Wales.	Scotland.	Ireland.	Total	England and Wales	Scotland.	Ireland.	Wales.
Under crops, including meadows, orchards, gardens and grass-lands	27,960,000	1,855,000	15,244,000	45,059,000	74·9	21·9	73·2	61·9
Woods and forests	1,620,000	829,000	332,000	2,790,000	4·4	4·3	1·6	3·6
Barren mountain land, bog, marsh, waste land, roads, water, fences, &c.	7,730,000	13,783,000	5,244,000	26,757,000	20·7	70·8	25·2	34·5
Total . .	37,310,000	16,467,000	20,820,000	77,601,000	100	100	100	100

The total area of waste lands, roads, water, fences, etc., amounts to 26,757,000 acres, of which about one-half is situated in Scotland. It is difficult to say what proportion of this area may be available or suitable for the growth of forest trees, but on the whole it may be assumed that the above-mentioned area of six millions of acres might be found, or at any rate the greater portion of it, because a good deal of so-called barren mountain and waste land is quite suitable for planting, and a large proportion of the bog and marsh can be rendered fit for tree growth by draining. On the other hand, a considerable part of the waste lands yields now so high a return as shooting grounds, that it might involve a financial loss if such areas were put under forest.

The 5,869,667 loads of timber imported annually, and which could be grown in the United Kingdom, came from the following countries :—

From Russia (northern ports) . .	1,333,139	loads.
„ Sweden	1,506,852	„
„ Norway	728,111	„
„ Germany	346,189	„
„ France	348,771	„
„ the United States of America .	373,089	„
Total . . .	4,636,151	„
„ Canada	1,233,516	„
Grand total . .	5,869,667	„

In round figures, the United Kingdom receives about $1\frac{1}{4}$ million of loads from a British colony—the Dominion of Canada—and upwards of $4\frac{1}{2}$ million loads from foreign countries, over whose forest policy the British Government has no control. The question thus arises, are these countries likely to keep up the supply? The reports received from Canada are not encouraging. Enormous areas of timber forests have been destroyed of late years, and the United States may at any date attract the surplus supply which is still available in Canada. It is beyond the scope of this work to discuss the question, in how far the British Government can influence the Government of Canada in introducing an efficient system of forest conservancy. The imports from this colony show a decline of 32 per cent. during the five years 1883—87.

The supplies received from the United States of America represent probably, as far as their bulk is concerned, material which came originally from Canada; hence it may safely be predicted that this supply will disappear, because the United States have to import timber on a large scale for their own requirements. All available information shows this.

The imports from France are believed to represent chiefly mining props received from the pine forests situated to the north and south of Bordeaux. The supply has, during the years 1883—87, increased by 9 per cent., and it seems capable of a considerable further expansion.

The imports from Germany have fallen off by 35 per cent. during the five years under discussion; this is probably due to the fall in the price of timber, and not to a falling off in the supply, as the bulk of the German forests is under systematic management and control; indeed, it is believed that future supplies to this country could be increased, especially from the forests in East Prussia.

In Sweden, Norway, and Russia, the forest conservancy measures so far introduced do not warrant a sustained yield from these countries. Of the Swedish forests only 20 per cent., and of the Norwegian 12 per cent., belong to the State, while little or no control is exercised over the rest of the areas. The United Kingdom has on an average received 3,568,102 loads from the above-mentioned three countries, the supplies having fallen off, during the period 1883—87, by 4 per cent. from Russia, 8 per cent. from Sweden, and 13 per cent. from Norway. If this decrease is not due to fluctuations in trade generally, but to a gradual exhaustion of the growing stock in the forests, this country may be seriously affected. No other countries are known at present which could replace the supplies hitherto received from the above-mentioned countries. India has nothing to spare, except a certain quantity of Teak and some fancy woods, which would be too expensive to replace the cheap woods now received from nearer home. Australia can probably do little or nothing to help.

On the whole, future supplies of timber to this country in sufficient quantity are by no means assured; and there is so much doubt about their continuity, that any woods now planted in the United Kingdom may reasonably be expected to yield a fair return by the time that they become ripe for the axe. At any rate, forethought as regards future supplies of timber is more necessary than in respect of any other article, since many years must pass before trees attain a sufficient size to yield timber for construction, shipbuilding, and such like purposes. The financial aspect of the question will always be one of great difficulty in this country. The State, or the Crown, owns a comparatively small area of the surplus land, and private owners will, as a rule, be guided by financial considerations. The latter have not, in many cases, the means to meet the initial cost of planting, fencing, draining, etc., or, even if they were to find that money, they may not be in a position to forego an income from the land, until the forests came into bearing. Hence they will not, as a rule, plant except on land which cannot be otherwise made to yield a reasonable return. At present the prices of timber are so low, while deer and game preserves pay such high returns, that timber forests on a large scale are not likely to be established, except in so far as they may be auxiliaries to improve the shooting.

3. *Labour.*

The labour question in connection with afforestation is of some importance in these islands. If the forest area were increased by 6,000,000 acres during the next twenty years, it would be necessary

to plant annually some 300,000 acres, which would fully employ at least 15,000 labourers (one labourer for twenty acres), corresponding to a population of 75,000 people. After the forests had been created, they would give steady employment to perhaps 100,000 labourers, corresponding to a population of half a million of people, apart from special forest industries, which the existence of extensive forests tends to create. Large as these figures are, they show that forests give but small employment, when compared with the cultivation of field crops on equal areas; it follows that, as regards the labour question, no lands required for field crops could be made available for forests. The latter must, in this respect, be restricted to surplus areas, as long as forest produce is obtainable at a reasonable rate from abroad. If, however, large numbers of people are in want of work, it would be a judicious measure to give them employment by afforesting available waste lands, a consideration which is of special importance to Ireland. With the exception of the duties performed by the administrative staff, the work connected with forest operations can be made to fit in with agricultural occupation, and the small cultivator, especially in the poorer parts of the country, can take advantage of every spare day to earn a day's wages by work in the forest, and so add to his income, which would be a substantial help in enabling him to meet the payment of rent, taxes, etc. As regards Ireland in particular, afforestation would prove to be a useful auxiliary in solving the land question, and through it, the ultimate restoration of peace and quietness in that country.

4. *Summary.*

In summing up, the following principal conclusions may be drawn in respect of Great Britain and Ireland.

(1.) As the imports of wood and other forest produce are very great, and as it is doubtful whether sufficient supplies can be permanently obtained from other countries, the extension of the forest area can be strongly recommended, provided it is carried out on surplus lands. The additional wood lands may reasonably be expected to yield fair returns on the invested capital, if the work of creation and administration of the forests is done in an economic manner.

(2.) The surplus area in the United Kingdom is so great, that extensive areas can be set aside for forests, without trenching on the land required for field crops.

(3.) The tendency of forests to reduce the temperature of the soil and the air, and to increase the relative humidity of the air and the rainfall, is of subordinate importance in these islands, as they are, owing to their geographical and sea-bound position, subject to influences, in comparison with which those of forests are small.

(4.) The increase of the forest area will act very beneficially in reducing the effects of winds on adjoining lands under cultivation, and in affording shelter to cattle and useful birds.

(5.) The extension of the area under forest will provide additional work, without interfering with existing sources of occupation.

It will be seen, that a fair field for judicious enterprise exists in the extension of the woodlands of Great Britain and Ireland on areas which do not yield a fair return if cultivated with field crops or used as deer and game preserves.

APPENDIX II.

FORESTRY IN BRITISH EAST INDIA.

It would be beyond the scope of this work to give here a detailed account of all those points on which the general forest policy of India must depend. A few short notes on the physical configuration of the country and its climate are however indispensable before dealing with the forest question itself.*

India is a very large country; it extends from the 8th to the 35th degree northern latitude, and from the 67th to the 100th degree eastern longitude. Its length from north to south is 1920 miles and its greatest breadth 1900 miles, irrespective of the newly-acquired territory of Upper Burma. On the whole, India is of a triangular shape, the Himalayas forming the base on the north, while the southernmost point is Cape Comorin. The triangular peninsula has the Arabian Sea on the west, the Indian Ocean on the south, and the Bay of Bengal on the east. Burma forms a separate strip of land on the east of the Bay of Bengal. The total area of the Indian Empire is given as 1,463,000 square miles, or about twelve times that of the United Kingdom, and the population as 255,000,000, or seven times that of the United Kingdom.

* Compare The Statistical Atlas of India, 1886.

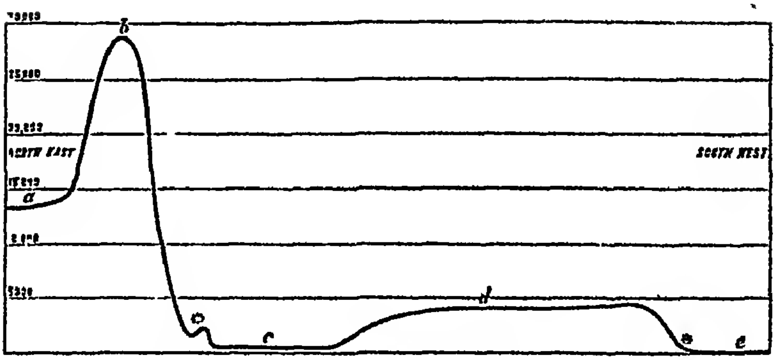
1. *Physical Configuration of the Country.*

The physical configuration of India is very peculiar. Generally speaking, the country may be divided into three great sections: the Himalayas, the Indo-Gangetic plain and the Peninsula.

The Himalayan range stands out like a high wall on the north, separating India from the high plateau of Thibet. It runs, commencing in the west, first in a south-easterly and then in an easterly direction from one end of India to the other; both on the west and the east, other ranges run almost due north and south. The space within these three ranges, and immediately to the south of the Himalayas, forms a broad belt of low land, commencing at Kurrachi on the Arabian Sea, in the west, taking in the whole of Sind, the Punjab plains, the greater part of Rajputana, the North-Western Provinces, Oudh, Behar and Lower Bengal down to the Sunderbuns beyond Calcutta, on the Bay of Bengal. In this belt of alluvial land, not more than a few hundred feet above the level of the sea, is found the bulk of the wealth of India.

Proceeding across this belt of low land in a southerly direction, stiff escarpments are met, indicating the commencement of the great highland plateau of the Indian Peninsula, which, at elevations varying from 2000 to 8000 feet, extends to the southern extremity of India. A section drawn from the Thibetan plateau in a south-westerly direction until it reaches the Indian Ocean at Travancore, would present the shape given in

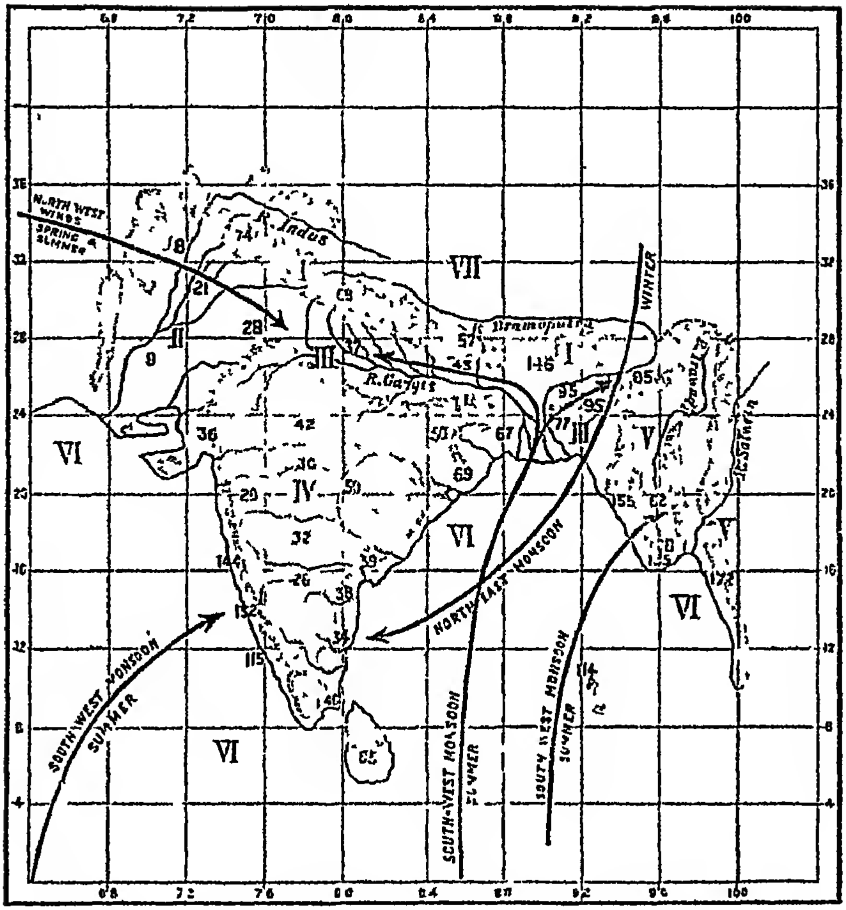
the subjoined sketch, except that the elevations have been exaggerated :—



a = Tibetan plateau, mean height about 11,000 feet.
b = Himalayas, maximum height 20,000 feet.
c = Indo Gangetic plain, height a few hundred feet above the sea.
d = Peninsula, height varying from 2,000 to 8,000 feet.
e = The Sea.
* = Points where the clouds coming from the sea must rise, cool and drop their moisture.

The sketch map on the next page gives an idea of the extent of each of the regions.

The river system of India next claims attention. It is a curious fact, that India receives the drainage of both slopes of the Himalayas. At the back of that mountain chain two great rivers take their rise in close proximity of each other; both run parallel to the Himalayas, the one in a north-westerly and the other in an easterly direction. The former breaks, after some time, through the Himalayas and emerges into the Punjab plain as the River Indus, finding its way, through Sind, into the Arabian Sea. The second river, after running for hundreds of miles to the north of the Himalayas, also breaks through that mountain chain and appears in Upper Assam as the Bramaputra, which proceeds down



I. Himalayas. III. Ganges Plain. V. Burma.
II. Indus Plain. IV. Peninsula VI. The Sea.
VII. Thibetan Plateau. 9. Mean annual Rainfall, in inches.

the Assam valley, through Lower Bengal, and joins the Ganges shortly before reaching the Bay of Bengal.

The southern face of the Himalayas is drained, in its western part, by the five Punjab rivers, which join the Indus. From Simla towards the east, first the Jumna and Ganges, which join at Allahabad, emerge from the hills, and the Ganges takes in a series of streams which drain the southern slopes of the range from the North-Western Provinces to Bhootan. The drainage of the Peninsula is arranged in the following manner:—The Ganges receives the drainage of the northern edge. Next two rivers, the Narbada and Tapti, run in close proximity into the Arabian Sea, while by far the greater portion of the plateau sends its water in an eastern direction into the Bay of Bengal.

The two principal rivers in Burma are the Irawadi and the Salwein.

2. *Climate and Rainfall.*

Owing to the great extent of country included in India and the varying conditions prevailing in the several parts, it is impossible to speak of the climate of India; it would be more correct to speak of the "*climates*," of which the following four types may here be indicated:—

(1.) The climate of Tropical India.
(2.) " of North-Western India.
(3.) " of North-Eastern India.
(4.) " of the Himalayas.

About one-half of the area of India, comprising the greater part of the Peninsula and Burma, is situated south of the tropic. These are the hottest parts of India, as far as the average of the whole year is concerned; but the highest temperature is reached further north. The early arrival of the summer monsoon rains mitigates the summer temperature in tropical India; on the other hand this region enjoys little or no cool season.

The second type of climate is found to the north of the tropic in the dry and almost rainless plain of the north-western corner of India, comprising the area which is traversed by the River Indus. Here the highest summer temperature is found, due to a greater length of day and a later arrival of the summer monsoon rains, than in tropical India; it is to some extent compensated for by four or five cool and even cold months during winter, representing at that time a climate which has been compared with a south Italian winter.

The third type of climate is found in Assam and North-eastern Bengal. Here humidity of the air reigns supreme; although there is a distinct summer and winter, in either case the extremes of temperature are moderated by the effects of a relatively large quantity of moisture in the atmosphere, which produces fogs in winter, and interferes in summer with the full effect of the sun's rays on the land.

Finally the Himalayan mountains present, according to the elevation and position of each locality, a more or less temperate and even arctic climate, with frost, snow, sleet and bitter winds in winter and a moderate heat in summer.

Between these four types any number of modifications are to be found. However large their number may be, and however much the various climates may differ, they are, apart from elevation, the result of a system of atmospheric changes, which are exceedingly simple and regular. The main-spring of the Indian climates is the fact, that the extensive plains and table lands of India are in spring and summer heated to a much higher degree than the surrounding sea; while during winter the air overlying the sea is warmer than that over the land, from which at that season of the year more heat radiates than it receives from the sun. The results are sea breezes during summer and land breezes during winter.

It will be useful to enter somewhat more into the details of these phenomena. In spring, which shall here comprise the months of March, April and May, the highest temperature is found over the centre of the Peninsula (Nagpur, Hyderabad), while it falls as much as 5 to 10 degrees in proceeding towards the sea on the east and west, and about 10 degrees proceeding to the foot of the Himalayas or to the Punjab plain. The effect is, that the air over the centre of the Peninsula expands, lifts the higher layers of air, causes them to flow away on all sides, and produces a centre of comparatively low pressure. Into this centre presses the heavier atmosphere from the surrounding country, especially from the sea, causing the sea breezes so characteristic of the spring months.

These air currents deviate however from their original course in consequence of the law that everything moving on the northern hemisphere presses towards the right. The consequence is, that the winds which hit the Madras

coast are mostly south-easterly breezes, those which hit the southern half of the west coast have a south-westerly direction, while those which hit the land to the north of Bombay assume gradually a more and more north-westerly direction. These phenomena have the result, that Madras and the southern part of Bombay are passed over by moist sea winds, which drop a portion of their moisture, producing a rainfall of from 3 to 6 inches during this period. The above-mentioned north-westerly breezes, however, descend from the table land of Baluchistan; they are dry and become more so in passing over the heated plains of Sind, Cutch and Kathiawar. These are the breezes which are known as the hot winds in the Bombay Presidency, in North-Western and Central India. At times they find their way as far as Bengal and Orissa, and far down into the Peninsula.

Up to May the sea winds are light, and they bring only a moderate amount of rain, as the air is then drawn chiefly from the sea immediately surrounding the Peninsula. With the advancing season towards the end of May, the winds become stronger and stronger, bringing more and more rain, until, in the course of three or four weeks, they have invaded the whole of the west coast of India and the northern and eastern coasts of the Bay of Bengal, an event which is known as the burst of the Monsoon. Now the air is drawn from more distant equatorial regions, the great reservoir of moist air.

The strength of the Monsoon rains differs enormously in different parts of India; it depends on the configuration of the country and the extent to which the sea

breezes succeed in overcoming and pushing back the north-westerly air currents. The Monsoon winds enter the Bay of Bengal from the south-west and they strike against the coast of Tenasserim in full force, rise, and pour out a copious rainfall. This holds good in a varying degree along the coast of Burma, in Chittagong, Cachar, and Assam. Along this line the rain-clouds meet with hill ranges at moderate distances from the shore, which cause them to rise and drop their moisture, while Lower Bengal receives a somewhat smaller rainfall. After passing through Lower Bengal and on approaching the Himalayan chain, that mountain-range opposes itself to the course of the current and divides it into two parts. The larger part continues its north-easterly course and hits full on the Garo, Khasi and Naga hills, producing the highest rainfall in the world (upwards of 500 inches at Cherrapunji), and finally giving a considerable rainfall to the Assam valley. The smaller part of the divided current is diverted towards the north-west and west, sweeps, and plentifully waters the face of the mountains and spreads a certain amount of rain over the plains of the North-Western Provinces and Oudh. Here then the summer Monsoon comes from the east, but it is occasionally displaced by a westerly or north-westerly current, when a shorter or longer suspension of the rainfall occurs, a phenomenon which will again be referred to.

On the west coast of the Peninsula the Monsoon blows directly athwart the coast line. As the western part of the Peninsula rises very rapidly from the sea to an elevation of up to 8000 feet at the Ghat range, the clouds are forced to rise, to cool and to drop an

enormous amount of rain. At the same time the western edge of the peninsular plateau is its highest part, and the clouds, or what remains of them, having overcome this, descend again in their easterly progress, and the rainfall diminishes rapidly on the eastern side of the Ghats to about one-sixth of that on the western slopes; this extends over a strip of 100 to 200 miles in breadth, and comprises part of the Deccan, the Mysore table land, and the Carnatic, areas which are most subject to drought.

Between the easterly course of the Peninsular Monsoon and the westerly course of the wind which, diverted by the Himalayas, rushes up the Gangetic plain, lies a broad belt of debatable ground, comprising part of the Central India States, the Satpura Range, the greater part of the Central Provinces, the table-land of Chutia Nagpur, Orissa, and Western Bengal. In this broad belt the rain-fall is higher than to the south or north-west of it, chiefly because numerous storms, generated near the coast of Bengal, travel along it from east to west, their passage being accompanied by heavy rain.

The country which lies to the north-west of this belt is, again, under the effect of the western branch of the Monsoon; part of this passes through Gujarat, Rajpútana, Cutch, and Sind, towards the Punjab, where it disgorges varying quantities of rain according to the configuration of the country. On the whole, however, the strong air-current from the west and north-west becomes more and more dry on proceeding north, as it no longer comes from the ocean, but successively from Arabia, Persia, Baluchistan, and Afghanistan; hence

the rainfall decreases most rapidly on proceeding north from Bombay.

As long as the sea winds are sufficiently strong to keep in check and even force back the north-westerly winds during summer, all is well; but every now and then the reverse is the case, that is to say, the north-west wind forces back the sea winds, and proceeds further and further east and south-east into the North-Western Provinces, Behar, and even Bengal and Orissa, or it forces its way down into the Peninsula. If it keeps its sway over the sea winds for some period, a failure of the Monsoon rains is the consequence, an event which is followed by scarcity or famine.

The copious watering of the surface of the land, in its turn, reduces the temperature, so that in some parts of the country the rainy season is actually the coolest time of the year. Indeed the reduction is almost proportionate to the rainfall. Hence, parts which receive little or no rain, as Sind, Western Rajputana, the southern part of the Punjab, and also the Carnatic, show the highest temperature during summer. On the other hand, the temperature of Assam is comparatively little affected, because here rain falls copiously even in spring.

In September the Monsoon commences to decline, but in Bengal and Burma the rains last well into October. In the beginning of the latter month the winds in the western part of the Bay of Bengal begin to blow from the north-east, and now for the first time the hitherto scantily-watered Carnatic receives a copious rainfall; these rains go on until December, when they gradually move southwards to Ceylon. They are followed by a dry steady north-east wind which gradually extends

over the whole Bay of Bengal, and is known as the north-east Monsoon. An easterly wind takes at that period possession of the Arabian Sea.

Meanwhile in Northern India the temperature, after a temporary slight rise on the cessation of the rains, has fallen rapidly during November and December, producing a cool air and cloudless skies. About the end of the year clouds begin to gather on mountain-peaks, warmer breezes from the south set in, the skies become overcast, followed by a fall of rain, or snow on the hills. Such winter rains are most frequent in the Punjab and the North-Western Himalayas, but occasionally they extend also to Bengal, Rajputana, and Central India. They become more frequent in January, February, and March. And then a new round of seasons sets in.

It is almost impossible to give in a limited space an adequate idea of the endless differences in the climate and rainfall. By way of illustration, the following table is added, in which a series of main groups have been formed. More detailed data must be looked for in the Reports of the Meteorological Reporter to the Government of India, from which the subjoined table has been compiled:—

ABSTRACT SHOWING THE CLIMATE AND

SPRING = *March, April, May.*

SUMMER = *June, July, August.*

Region	Temperature, in Degrees Fahrenheit.				
	Spring	Summer.	Autumn	Winter.	Year
Himalayas . .	59	71	58	42	58
Indus Plain . .	83	90	77	60	77
West Gangetic Plain . .	84	87	77	62	78
East Gangetic Plain and Assam . .	80	83	78	65	77
Peninsula: Northern Edge . .	82	80	73	62	74
Peninsula: West Coast and Ghats	78	74	74	72	75
Peninsula: Centre	88	82	77	73	80
Peninsula: East Coast . .	85	85	81	77	82
Burma . . .	83	79	79	73	79
Bay Islands . .	82	80	80	79	80

RAINFALL OF THE DIFFERENT PARTS OF INDIA.

AUTUMN = *September, October, November.*

WINTER = *December, January, February.*

Region.	Mean Annual Vapour Tension, in Inches.	Mean Annual Relative Humidity in per cent. of Saturation	Rainfall, in Inches.				
			Spring.	Summer.	Autumn.	Winter.	Year.
Himalayas . . .	·332	73	11	61	16	5	93
Indus Plain . .	·483	47	2	14	3	2	21
West Gangetic Plain . .	·569	62	2	26	8	1	37
East Gangetic Plain and Assam . .	·748	80	15	43	17	2	77
Peninsula: Northern Edge . .	·477	54	1	31	9	1	42
Peninsula: West Coast and Ghats	·700	79	6	103	22	1	132
Peninsula: Centre	·561	56	3	22	10	1	36
Peninsula: East Coast . . .	·738	67	5	12	18	3	38
Burma	·787	77	14	81	29	1	125
Bay Islands . .	·871	81	20	43	39	12	114

3. *Distribution of Forests.*

If such evidence, as is now available, can be relied on, the greater part of India was in former times covered with dense forests. In those days the country was probably more fruitful and the climate less fierce than now. In the fourth century Fa-Hian, the great Chinese traveller, described the climate as neither hot nor cold. Subsequently, settlers opened out the country along fertile valleys and streams, but the destruction of the forests on a larger scale was done by Nomadic tribes, which, moving from pasture to pasture, fired alike hills and plains wherever they went. This lasted for more than 750 years. With the advent of British rule, the destruction of the forests became more fierce than ever. The order of the day then became "extension of cultivation at the cost of the still existing forests," a process which was carried out for many years, without any enquiry as to the ultimate effects. To this was gradually added an increasing demand for timber and pasture for rapidly multiplying herds of cattle, which roamed far and wide over the remaining forests. To crown the edifice, Railways then came, and with their extension the forests disappeared with greater rapidity than ever, partly on account of the increased demands for timber and firewood used in construction, and partly on account of the fresh impetus given to cultivation on both sides of the lines.

Ultimately, when failures to meet the demands for public works were brought to notice, it was recognized that a grievous mistake had been made, in allowing the forests to be recklessly destroyed. First, half-hearted

measures were adopted to stop the mischief, and when their insufficiency was recognized, a special State Department was organized to grapple with the existing evil. This event took place about thirty years ago.

The first duty of the new Department was to ascertain the extent of the remaining forests, and more especially that portion of them which was still the property of the State. India is a country of extremes as far as climate and rainfall are concerned. The latter more especially governs the natural distribution of the forests. While Jacobabad, in Sind, has a rainfall of 4 inches a year, Cherrapunji, in the Khasi Hills, can boast of a fall exceeding 500 inches a year. Where rainfall and temperature are favourable, the reproductive power of the forests is great; where they are unfavourable, reproduction proceeds only at a slow rate. During the long continued struggle between human action and the effort of self-preservation on the part of the forests, the latter succumbed wherever the climatic conditions were unfavourable; hence, what remained of forests thirty years ago, was situated in the localities with a heavy rainfall, or where a scanty population had carried on only a feeble warfare against the woodlands.

Again, the nature of the rainfall governs the character of the forests. Where the Monsoon rains are heavy, the country is generally covered with evergreen forests; where the rainfall is less copious, the forests are deciduous; under a still smaller rainfall, the forests become sparse and more dry, and gradually end in deserts. Thus the evergreen forests are found along the moist coast of the Peninsula, in the coast districts of Burma and Chittagong, and along the foot and lower

slopes of the eastern Himalayas. The deciduous forests occupy the greater part of the Peninsula, and of Burma away from the coast; they are the home of the Teak, Sal, Sandal-wood, Red Sanders, Iron-wood, Padouk, and others. Dry forests are found in Rajputana and the Punjab, and they gradually disappear in the deserts of Sind.

With rising elevation in the hills, more especially in the Himalayas, the forests become gradually temperate and then alpine. The other extreme are the tidal forests found along the greater part of the coast of India and in the deltas of the rivers.

4. *Area of Forests.*

India is not all British territory; a large portion belongs to native rulers. Apart from the newly acquired territory in Upper Burma, the total area is divided in the following manner:—

—	Area in Square Miles	Population.	Density of Population per Square Mile
British Territory .	912,000	202,000,000	210
Native States . .	551,000	53,000,000	97
Total . .	1,463,000	255,000,000	175

These are vast areas. Nevertheless, a considerable amount of statistics has been collected in the British territory, but less is known regarding the forest areas in the Native States. On the whole it may be said, that about 25 per cent. of the British territory is covered with forest of some kind, and the same proportion may perhaps hold good as regards the Native States.

With a few exceptions little or no control has hitherto been exercised over the forests in the latter States. In British territory about half the forest area belongs to the State, and the other half to private persons. The State control over the latter is at present nil or nominal.

The management of the State forests has undergone a great change during the last thirty years. Of the total area of Government forests, which may perhaps amount to some 70,000,000 of acres, 55,000,000 have been brought under the control of the Forest Department. Of this area 33,000,000 are so-called reserved State forests, that is to say, areas which, under the existing forest law, have been set aside as permanent forest estates, while the remaining 22,000,000 are either protected or so-called unclassed State forests. These areas together comprise about 11 per cent. of the total area of the provinces in which they are situated. Rather more than half the area, or about 6 per cent., are strictly preserved and systematically managed forests. The other 5 per cent. enjoy as yet only a limited protection, but it rests with the State to perfect that control at any time, as far as existing rights allow of this being done.

The subjoined table gives the details for the several provinces. Similar data for Upper Burma are not yet available, but that province is known to contain very extensive and valuable Teak forests :—

Province	Government Forests under the control of the Forest Department, on the 1st April, 1887, in Acres					
	Reserved	Protected	Unclassed.	Total	Percentage of Total Area of Province.	Average per Head of Population
Bengal	3,101,000	1,405,000	2,351,000	7,177,000	7	10
North Western Provinces and Oudh	2,2[illegible]0,000	47,000	84,000	2,[illegible]91,000	4	·05
Punjab	769,000	211,000	2,091,000	3,101,000	5	·0
Central Provinces	12,771,000	.	[illegible]	[illegible]	21	1·[illegible]3
Burma (Lower)	3,061,000			[illegible]	6	·34
Assam	1,782,000	7[illegible]4,000	3,521,000	[illegible],437,000	22	1·31
Coorg	155,000		.	155,000	15	·67
Ajmere	[illegible]			[illegible]	5	·11
Berar	957,000		1,[illegible]	2,[illegible]50,000	23	·[illegible]9
Madras	2,163,000	4,78[illegible],000	70[illegible],000	7,[illegible]51,000	14	·25
Bombay	6,211,000	2,[illegible]7[illegible],000		8,11[illegible],000	11	·[illegible]
Total	[illegible],424,000	10,147,000	11,30[illegible],000	[illegible]4,874,000	11	·27

5. *Forest Policy in India.*

In former times certain forests were carefully protected as game preserves for the pleasure of kings, princes, and great nobles. These areas were of small extent when compared with the area of the country. The idea of preserving forests for the supply of timber, fuel and other forest produce, or on account of their indirect effects on climate, rainfall, the regulation of moisture, the stability of the soil on sloping ground, etc., is of modern origin, as has already been pointed out above. Under the policy of the Government of India, as developed during the last twenty-five years, an area equal to 11 per cent. of the total area of the country has been placed under State management, and the question arises, whether the Government of India has gone too far in this matter, or not far enough, and if the latter, what further steps should be taken.

It would lead too far to discuss this question here in all its details, but the main issues may be shortly touched

upon. It is necessary, then, to consider chiefly the following points:—

(*a.*) Forests in relation to Climate and Rainfall.
(*b.*) The Regulation of Moisture.
(*c.*) Forest Produce required by the Country.

a. Forests in Relation to Climate and Rainfall.

The relation between forests and the climate and rainfall of India is of a very peculiar nature. On the one hand, a covering of forest vegetation reduces the temperature of the air and soil, increases the relative humidity, and tends to increase the rainfall, while on the other hand the exceptionally high temperature which prevails in spring and early summer over the centre of the Indian peninsula brings about the summer Monsoon rains, on which the welfare of India depends. In other words, extensive afforestation might increase the quantity of locally formed clouds and produce local rainfalls, but it might also weaken the force of the south-west Monsoon winds and consequently the accompanying rainfall. It is perhaps difficult to say what the ultimate effect of a general afforestation might be, but it may reasonably be assumed that the effects of forests, however extensive, are not likely to produce a quantity of rain, which would make up for any weakening of the south-west Monsoon. As a matter of fact, however, more than half the area of Madras, Bombay, the North-Western Provinces, and Bengal is under cultivation, and a considerable additional area has been appropriated as grazing grounds, so that not more than one-fourth could remain under forest, an area, which may be

sufficient to moderate the temperature locally, but which is not likely to interfere with the advent of the annual south-west Monsoon. The latter must for ever be the main source of moisture in India. Apart, however, from these theoretical speculations, it has yet to be proved, whether afforestation in low or level lands affects the rainfall at all. The extensive observations made of late years in Europe, have not yet led to any final conclusions, and those carried out in India have not extended over a sufficient number of years to permit of any conclusions at all. In India three cases of evidence have been mentioned *:—*First*, a steadily increasing rainfall in the southern half of the Central Provinces, since 1875, when temporary cultivation was stopped, and fire protection on a large scale introduced into the extensive forests of that region; *secondly*, the result of observations made at two parallel stations established in the Dehra Dun; *thirdly*, the abnormally large rainfall in the Changa Manga plantation in the Punjab. In each of these three cases the presence of a dense forest growth seems to accompany an increased rainfall, but there are substantial reasons why a final conclusion does not seem justified.

In the case of the Central Provinces it has been shown that the rainfall in and around the forest reserves has increased since 1875 by about 20 per cent., as compared with the ten years previous to 1875. Against this can be brought forward :—

(1.) Some of the stations in the very centre of the forest reserves show a comparatively small increase.

* Compare a paper read before the Asiatic Society of Bengal on the 2nd February, 1887, by Mr. Henry Blanford, F.R.S., Meteorological Reporter to the Government of India.

(2.) Several of the stations which show a specially large increase are either situated far from the reserves, or in their vicinity little forest conservancy has been effected.

(3.) The general rainfall of India, as represented by the meteorological returns, shows a steady progressive increase since 1875, though not so great as that in the Central Provinces.

(4.) It has been officially announced, quite lately, that the returns from the Central Provinces before 1875 are not reliable, and that in many cases new and more accurate instruments have been introduced during the period over which the observations extend.

(5.) On the whole it is not likely that the rainfall of India generally has increased since 1875; it is much more probable that the apparent increase is due to progressively more accurate and complete observations, an improvement which may have been specially rapid in the Central Provinces.

The two years' observations made in the Dehra Dun parallel stations (one inside and one outside the forest) indicate an increased rainfall in the forest, but the period of observation is much too short to admit of any conclusion being drawn at present.

The excess of rainfall noticed in the Changa Manga plantation over that recorded at outside stations, amounts to 6 per cent. In how far this is due to the presence of the forest, or to the fact that the area is regularly irrigated, it is difficult to say.

On the whole there can be no doubt that, even under the most favourable circumstances, the climate and rainfall of the Indian plains are subject to other influences,

compared with which the effect of a limited forest area must always be very small. At the same time it need scarcely be mentioned how gratefully the shade and shelter of forests will be accepted by man and beast in a country as hot as India.

b. Regulation of Moisture.

It will easily be understood that the regulation and proper husbanding of the available moisture must be of great importance. As far as forest vegetation assists in this, the subject must be considered chiefly from two points of view:—

(1.) In respect of the evaporation of moisture; and
(2.) In respect of the mechanical action of forests.

The difference in evaporation from an area exposed to the full effects of the sun, and another sheltered by a dense growth of forest vegetation, must be much greater in a tropical country like India, than it has been proved to be in a temperate climate. Hence the presence of forests must act highly beneficially wherever the rainfall is limited, or unfavourably distributed over the seasons of the year; in other words, especially in the Indus and West-Gangetic plain and in the drier parts of the Peninsula.

There is, however, a second way in which forest vegetation acts most favourably, namely, as a help towards successful irrigation. Of the 199,500,000 acres which are cultivated annually in India, no less than 30,000,000 acres are artificially watered either by canals, or from wells, lakes, and tanks. Some of the canals are fed with water derived from the enormous snow fields of

the Himalayas, and the rest with water which comes from other sources. Accordingly the irrigated area may be classified as follows :—

Area irrigated from			snow-fed canals	3,000,000	acres.
"	"	"	other canals .	5,000,000	"
"	"	"	wells . .	13,000,000	"
"	"	"	other sources .	9,000,000	"
			Total . . .	30,000,000	"

Only 3,000,000 acres, equal to 10 per cent. of the total irrigated area, rely directly on the melted snow of the Himalayas. Of the 13 million acres irrigated by well-water, 10½ millions are situated in the Indo-Gangetic plain. The wells in this plain may be said to tap great underground reservoirs underlying the plain. Part of this water may come from melted snow, but the greater portion consists no doubt of the rain water which sinks into the ground.

The remaining 16½ millions of acres derive their water from the rain which falls on the heated surface of low lands and moderately high hills. The larger the proportion of the catchment areas, whence this irrigation water comes, which is shaded by forest vegetation, the more favourable and sustained will be the supply of water. Here then is a mission which forestry in India has to fulfil.

The mechanical action of forest vegetation on sloping ground, also, is not without importance in India. There is sufficient evidence to show what careless or injudicious clearing of forests may do. Anyone who has ever stood on the hills behind Hushiarpur in the Punjab, and looked down upon the plain stretched out towards the

south-west, has carried away an impression which he is not likely to forget. In that part the Siwalik range consists of an exceedingly friable rock, looking almost like sand baked together. Formerly, the range was covered with a growth of forest vegetation, but a number of years ago cattle owners settled in it, and under the combined attacks of man, cows, sheep, and goats, the natural growth disappeared, while the tread of the beasts tended to loosen the soil. The annual Monsoon rains, though not heavy, soon commenced a process of erosion, and of carrying away the surface soil. Gradually small, and then large ravines and torrents were formed, which have torn the hill range into the most fantastic shapes, while the *débris* has been carried into the plains, forming, commencing at the places where the torrents emerge into the plain, fan-shaped accumulations of sand, which reach for miles into the plain, and which have already covered and rendered sterile extensive areas of formerly fertile fields. Indeed, one of these currents or drifts of sand has actually carried away a portion of the town of Hushiarpur. The evil has by no means reached its maximum extent,* and if curative measures are not adopted at an early date, the progress of transporting the hill range into the plain will go on, until the greater part of the fertile plain stretching away from its foot has been rendered sterile. To cure the evil, it is necessary to stop grazing, at any rate that of goats and sheep, so as to allow the hills to re-clothe themselves with a covering of plants, shrubs, and trees, and to help by artificial sowing and planting wherever required.

* See Baden Powell's pamphlet.

Although the case of the Hushiarpur Chos, as they are called, is the worst of its kind in India, there are other instances which prove that afforestation is essential on hill sides, wherever the rock is friable and liable to be carried away by the continued action of water. It would, however, be a mistake to assume that every hill slope requires to be under forest. Over considerable areas the rock is firm, and capable of holding its own without the steadying help of a growth of forest vegetation.

c. Forest Produce required in India.

Although India has an extensive sea-board, along which forest produce can be landed, it does not derive so much benefit from this fact as might be assumed at first sight, because it is such a vast country. The distance between the sea-shore and the places of consumption in the interior of the country amounts frequently to many hundred miles; railways are not as common as they are in England, and forest produce is a bulky article; hence only the coast districts would profit by the more ordinary classes of imported forest produce, even if they could be brought in sufficient quantities from other countries. Apart, however, from a certain number of railway sleepers and a limited quantity of timber, such produce from other countries is not available. By far the greater part of India must rely on the timber and fuel produced in the country.

The iron industry of India is at present almost nil, so that the bulk of iron and steel is imported; hence their use is much more restricted than in England, timber being, as a rule, used in their place. Although con-

siderable beds of coal exist in the country, they are very inconveniently situated, so that coal is at present chiefly used for industrial purposes; and certain railway lines even now use wood in the engines, owing to the high price of coal in consequence of the long haulage.

All the teeming millions of India use wood fuel in their domestic firing, and, if such is not available, dried cow-dung. Their using coal is out of the question for a long period to come, even if it was available, because the ordinary Indian cultivator has neither the necessary firing arrangements, nor could he afford to pay for the coal.

For domestic firing, India requires to maintain enormous areas under wood, which will be more than doubled if the annual requirements of timber for construction, boat-building, tools, agricultural implements, public works, railways, etc., are added. Judging by the standard with which continentally situated countries in Europe furnish us, it may safely be estimated that India should permanently maintain a forest area equal to half an acre per head of population, or, in a round figure, 100,000,000 acres in the British provinces, in order to secure a sufficient quantity of timber and firewood. That area would be equivalent to 17 per cent. the total area of the British provinces.

Apart from timber and firewood, the Indian forests have to supply a great variety of other, or minor, produce, and in many instances forests must be maintained for their indirect advantages, so that the minimum forest area may perhaps be estimated at 20 per cent. of the total area.*

* Russia and Sweden have 42 per cent.; Austria proper, 33: Hungary, 29 per cent.; Germany, 26 per cent.; Norway, 25 per cent., Italy, 22 per cent.; France, 16 per cent.

d. Conclusion.

History has proved that the preservation of an appropriate percentage of the area as forests cannot be left to private enterprise in India, so that forest conservancy in that country has for some time past been regarded as a duty of the State. Special forest laws have been passed under which about 6 per cent. of the total area have been brought under efficient conservancy, while another 5 per cent. receive a certain amount of protection; all these lands are Government forest estates. Interference with private forests always has met and always will meet with great difficulties, so that such interference should be restricted to cases of absolute necessity. Although it is not necessary to acquire as State forests the whole of the required 20 per cent. of the total area, it seems highly desirable, that at least half that area, or say 50,000,000 acres, should be constituted permanent forest estates and managed in a systematic manner. It rests with the Government of India to do this, by increasing the area of the already constituted forest reserves from 33 to 50 millions of acres, an area which is less than one-third of the total area of forests and waste lands, which is still the property of Government.

In carrying out such a policy special attempts should be made to raise the area of permanent State forests in those provinces, where the percentage is as yet small, more especially in the Punjab, North-Western Provinces, Burma, Madras, and Bengal. In most of these provinces, the necessary areas are available. Owing to the permanent settlement in Bengal it will not be possible to

create a sufficient area of State forests in that province, except by acquiring additional lands.

So far the Government of India has good reason to be satisfied with the financial results of its forest administration. The net revenue, after meeting all expenses of the Department, has been as follows since 1864, the year in which the Department was first established as a general State Department:

					£
1864 to 67,	average	annual	net	revenue	=106,615.
1867 to 72	"	"	"	"	=133,929.
1872 to 77	"	"	"	"	=212,919.
1877 to 82	"	"	"	"	=243,792.
1882 to 87	"	"	"	"	=384,752.

The annual net revenue during the period 1882—87 was nearly four times that of the period 1864—67, and the increase is going on with undiminished rapidity. There is little doubt, if any, that 25 years hence the net surplus will be four times the present amount if the Government of India perseveres in its forest policy as developed in the past. Indeed it would not be going too far to say, that the increasing forest revenue bids fair to become a substantial set-off against the expected loss of the Opium revenue, a loss which may occur some day.

This is the legacy left to the Treasury of the Indian Empire by the men who directed its forest policy during the last 25 years.

PART II.

FUNDAMENTAL PRINCIPLES OF SYLVICULTURE.

INTRODUCTION.

Sylviculture means the culture of forests, that is to say, all measures connected with the creation, preservation, and treatment of forests. In practice, however, the word Forestry is used to express and comprise all this, while under Sylviculture is understood the creation, regeneration, and tending of forests, or woods, until they become ripe for the axe. Sylviculture, as here defined, teaches how a forest, or wood, can be produced, so as to realize, in the most advantageous manner, the object for which it is created.

The object for which a particular forest is maintained depends on the will and pleasure of the owner, in so far as his freedom of action is not limited by rights of third persons, or by legal enactments. The object itself can be one of many, and of these the following may be mentioned by way of illustration:—

(1.) To yield produce of a definite description, for instance trees and shrubs of special beauty, or trees giving a certain kind of timber, or other produce fit for particular purposes.

(2.) To produce the greatest possible quantity of wood, or other produce, per acre and year.

(3.) To produce the highest possible money return per acre and year.

(4.) To produce the highest possible interest on the invested capital.

(5.) To produce certain indirect effects; for instance to influence the climate, to regulate the drainage of the country, to prevent landslips, avalanches, etc.

In each of these and other cases, the particular species of tree to be grown and the method of treatment are likely to differ, and it is the business of the Forester to select those species and methods which realize the object of management most fully and in the most economic manner. More especially, the Forester must always consider what effect the species and the selected method of treatment are likely to have on the property, and he must remember that, any exceptional strain put upon the soil for more than a limited period in order to realize an exceptional effect must be followed by a corresponding period of relaxation. Unless this is secured, the soil, in the majority of cases, will deteriorate, and it may ultimately become absolutely sterile. Such an exceptional strain may suit the special requirements of a particular owner, but is not in the interest of the general community. Political Economy teaches, that the correct mode of procedure points to the careful preservation of the productive powers (or factors) of any given locality, so as to render possible the production of the same effect, or even an increased one, regularly and indefinitely.

Science and experience show that in Forestry the safest method of preserving the productive powers of a locality consists in maintaining uninterruptedly a crop of forest vegetation on the area. The more frequently and the longer the ground is uncovered and exposed to the full effects of sun and air currents, the more, in the majority of cases, is the productive power liable to be reduced. The

justification of this theory will be found in the first chapter of this Part of the Manual.

The natural forest vegetation of the various parts of the earth consists of a large number of species of trees and shrubs, each of which has its peculiar mode of growth, and thrives best under certain conditions. Only certain species of trees possess the faculty of forming by themselves healthy and flourishing woods, while others will only obtain perfection if they are mixed with the former. Species are called *"ruling"* or *"dependent,"* according to whether they belong to the first or second category. Owing to the great number of species, and the ever-changing conditions in different parts of the earth, it would be altogether impracticable to deal with all in a book which has for its object to teach the theory of Sylviculture. The fundamental principles of Sylviculture hold good all over the world, but the illustrations must be taken from a limited area. In the present volume they will be taken from the timber trees ordinarily growing in Western Europe on the 50th degree of northern latitude, and the countries immediately to the north and south of it. If the more important species of timber trees growing in that region are classified in accordance with what has been said above, the following lists are obtained:—

Ruling Species.

Decidedly Ruling.—Spruce, Silver Fir, Beech, Scotch Pine.

Conditionally Ruling.—Oak, Larch, Common Alder, Birch, Willow.

Dependent Species.

Of these may be mentioned: Ash, Maple, Sycamore, Sweet Chestnut, Hornbeam, Aspen, Elm, Lime, White Alder, Weymouth Pine, Black Pine, Cembran Pine, Mountain Pine, etc.

Although the biological characteristics of these and other species have been carefully studied for many years past, the subject has been by no means exhausted, because the factors which affect the growth of trees vary constantly, and moreover some of these factors are as yet imperfectly understood. The experience which has been gathered will be found in the succeeding chapters. It is that experience which must guide the Forester in the selection of the species for a particular locality, and of the subsequent method of treatment.

The subjects which claim attention will be dealt with in the following four chapters:—

CHAPTER I.—LOCALITY IN RELATION TO FOREST VEGETATION.
" II.—THE DEVELOPMENT OF FOREST TREES.
" III.—CHARACTER AND COMPOSITION OF WOODS.
" IV.—THE SYLVICULTURAL SYSTEMS.

These are matters which govern all forest operations, not only the creation, regeneration, and tending of woods, but also the determination of the yield, the preparation of working plans, and the ultimate utilization of the forest produce; hence it seemed justifiable to place them together in a separate part, instead of in the next volume, which deals with the Creation, Re-

generation, and Tending of Woods, or Sylviculture proper.

The works which were chiefly used in the preparation of this Part are :—

(1.) Hartig, "Lehrbuch für Förster," first volume, 11th edition, 1877.

(2.) Heyer, "Der Waldbau," 3rd edition, 1878.

(3.) Gayer, "Der Waldbau," 2nd edition, 1882.

The "Encyklopädie by Hess, part 2," came to hand after this part had been written; it has been utilized in a few cases, in revising the manuscript.

Boppe's "Traité de Sylviculture" was received too late to be utilized on this occasion.

CHAPTER I.

LOCALITY IN RELATION TO FOREST VEGETATION.

When a plant germinates on the surface of the earth, it sends its roots into the soil, and its stem into the air. The soil, assisted by the subsoil, provides to the plant the means of stability and nourishment; the atmosphere overlying the soil furnishes certain nourishing substances, heat, light, and moisture. Hence soil, including subsoil, and atmosphere are the media which act upon forest vegetation, and they together are in Sylviculture called the "*locality*." The active agencies, or factors, of the locality depend on the nature of the *soil and the climate*, the latter being governed by the situation. The sum total of these factors represents the quality or yield capacity of the locality. The forester requires to be well acquainted with the manner in which soil and climate act on forest vegetation, in order to decide in each case which species and method of treatment are best adapted, under a given set of conditions, to yield the most favourable results. The detailed consideration of the laws which govern this branch of Forestry finds a place in the auxiliary sciences, such as Physics, Chemistry, Mineralogy, Geology, and Climatology. The subject is, however, of such importance, that an enumeration of the more important points appears justified, before proceeding to explain their effect on forest vegetation.

Accordingly this chapter has been divided into the following sections:—

Section I.—The Atmosphere.
" II.—Climate.
" III.—Soil.
" IV.—Effect of the Soil on Forest Vegetation.
" V.—Effect of Forest Vegetation on the Locality.
" VI.—Assessment of the Quality of the Locality.

Section I.—The Atmosphere.

The earth is surrounded by a column of elastic airy bodies, which moves with it, and which is called the atmosphere. Owing to the weight of its component parts, the atmosphere is densest close to the surface of the earth, and it becomes thinner with increasing distance from the earth, until it passes gradually into space.

The atmosphere consists essentially of the following substances:—

(1.) Atmospheric air.
(2.) Carbon Dioxide.
(3.) Water, in various conditions.
(4.) Solid bodies.
(5.) Ammonia.

1. *Atmospheric Air.*

The atmospheric air consists of a mechanical mixture of 21 parts of Oxygen with 79 parts of Nitrogen. No

chemical process is required to separate one constituent from the other; as a matter of fact, all porous bodies possess the faculty of taking Oxygen from the atmosphere, without entering into a chemical combination with it. Amongst such bodies are the soil and the leaves of plants. Whether Nitrogen is similarly taken up has not yet been proved, but further investigation may lead to important discoveries in this respect, as it is unlikely that the large store of Nitrogen should only serve as a dilution of the Oxygen.

Although the leaves of plants take up Oxygen during the night and in the shade, they exhale greater quantities of it under the effect of light; the latter is the result of the decomposition of Carbon Dioxide by the leaves, which retain the Carbon and again surrender the Oxygen. Thus, plants are powerful agents in the production of Oxygen.

The action of the air in the soil is chiefly two-fold; it causes the evaporation of moisture, and the decomposition of organic matter. The air which penetrates into the fissures and interstices of the soil becomes laden with vapour and with Carbon Dioxide; it is then forced out of the soil by every rise of temperature during the day, and replaced by fresh air during the cooling of the night. The extent of this change of air depends on the degree of porosity of the soil and the daily range of temperature; the greater these are, the more rapidly will moisture and organic matter (humus) disappear. Hence the importance of a loose soil. The daily range of temperature is seriously affected by the degree of protection which the soil receives from forest vegetation; it is greatest in fully exposed soils, and smallest in soils which

rest under the shelter of a crowded crop of trees, especially if the foliage offers lateral as well as vertical shelter against sun and air currents. In the latter case the humus is carefully preserved, in the former it disappears rapidly.

2. *Carbon Dioxide.*

The atmosphere contains up to 0·0004 of its volume of Carbon Dioxide, which is received from a variety of sources, as combustion or decomposition of plants, the breathing of animals, volcanoes, spring-water issuing from the interior of the earth, combustion of coal and lignite, from various minerals, as for instance Calcium Carbonate. Of these, the first is by far the most important source of supply.

Plants take the great bulk of the Carbon Dioxide which they require through their leaves from the atmosphere; only a comparatively small portion is taken up through the roots. Subsequently, when they die and are decomposed, their Carbon is converted back into Carbon Dioxide, and returned to the atmosphere; hence plants form an important link in the movement of Carbon Dioxide.

3. *Moisture.*

The atmosphere is the medium through which the dry land receives the greater part of the necessary moisture. Sheets of water (the sea, lakes, rivers, etc.) and moist bodies evaporate moisture which, as vapour, rises in the atmosphere, until it is again condensed into water. It either settles as dew on cool objects, or falls as rain, snow, or hail from the cloud region to the ground.

Plants being moist bodies, take part in the movement of moisture; they receive it from the soil through the roots, and evaporate it through the leaves.

In this eternal circular motion of moisture, several points are of special interest to the forester. In order to convert water into vapour, it must combine with heat; the consequence is, that evaporating bodies become drier and cooler, and, in their effort to replace the expended heat, they reduce the temperature of the surrounding layers of air. It follows that the rate of evaporation is, amongst other influences, governed by the temperature, in other words by the climate. There is, however, another reason why the rate of evaporation depends on the temperature:—The maximum of vapour which the air can hold, at saturation, rises at a more rapid rate than the increase in temperature. If, for instance, one cubic foot of air is saturated with vapour when it contains ·15 grammes of water at freezing point (32° F.), it can hold ·28 grammes at a temperature of 54½ degrees, and ·64 grammes at 77 degrees. It follows that air of a high temperature can hold more vapour than at a low temperature, and yet the relative humidity may be smaller in the former case. Hence evaporation is more rapid in summer than in winter; it is also greater during the day than at night.

4. *Solid Bodies.*

The atmosphere always contains a certain amount of organic and inorganic solid bodies, which are kept in suspension in consequence of their minute size and lightness. When vapour is condensed and falls to the ground as rain, snow, or hail, it carries with it a certain

quantity of these solid bodies, which differs according to locality; the mineral part of these deposits is not inconsiderable compared with that which is required annually for the production of timber on a fully stocked area. Amongst the substances thus brought to the ground are Calcium Carbonate, Magnesium Carbonate, Sodium Chloride, Calcium Sulphate, Ferric Oxide, Alumina, Silica, Organic Nitrogenous matter, etc. Direct analysis has shown that upwards of 300 lb. of these substances have been deposited on an acre of land in one year, a quantity more than sufficient to provide for that contained in a heavy increment of wood laid on during the same period. In other cases, observations have shown the quantities to be considerably less than 300 lb. per acre.

5. *Ammonia and Hydrogen Nitrate.*

Limited amounts of these important substances are contained in the atmosphere. They are required by forest plants in considerable quantities, especially in the formation of seeds.

A certain quantity of Ammonia and Hydrogen Nitrate is contained in the annual rainfall, but it is not sufficient to meet all the requirements of a forest crop. How the balance is obtained has not yet been ascertained.

SECTION II.—CLIMATE.

Under climate are understood the different local peculiarities of the atmosphere in respect of temperature, degree of clearness, moisture, and rest or motion. It has already been indicated, that the climate of a locality depends on its situation.

The climate of a locality is of greater influence upon the life and growth of plants than the degree of fertility of the soil; hence it demands the forester's special attention. Generally speaking, the climate of a locality depends on:—

(1.) Latitude and longitude, or geographical position.
(2.) Elevation above the level of the sea.
(3.) Aspect and gradient.
(4.) Shape of the surface and condition of surroundings.

Each of these affects the heat, light, and humidity of a locality, or the agencies which determine the commencement and progress of the annual phenomena of vegetation.

1. *Heat.*

Heat affects plant life in various ways. In the first place, it is necessary for evaporation by the plants and from the surface of the earth; and secondly, it governs the movement of the air, which produces a thorough mixture of its different ingredients, as well as that of warm and cold, dry and moist, clear and hazy air.

As plants have in general no internal source of heat, that required for evaporation must be supplied to them by the atmosphere, either direct or through the soil. If these are themselves deficient in heat, evaporation must cease as soon as the plant has expended the store of heat contained in its body. The latter, however, frequently does not take place until serious damage has been done to the plant, in other words, the temperature of the plant may be so far reduced that the freezing point is

reached, although the temperature of the surrounding air is as yet several degrees above that point.

The only important source of atmospheric heat is the sun, and the temperature of a locality depends in the first place on its *latitude*. The mean annual temperature decreases with the distance from the equator, because the sun's rays strike the earth more slantingly in proceeding north or south from the equator towards the poles. The climate thus produced is frequently called the *geographical* or *solar climate*. It exists nowhere on the earth, as it is modified and converted into the *physical* or *local climate* by a series of influences, amongst which the following deserve attention :—

a. Elevation above the Level of the Sea.

The temperature falls with elevation above the sea. In the Alps the fall is one degree for every 300 to 400 feet of elevation; it is about 900 times as rapid as the fall caused by increasing latitude. The effect of elevation upon temperature is subject to modifications. High plateaux of considerable extent show a milder climate than that calculated for their elevation, because the sun's rays are more intense than at the level of the sea. On the other hand, wind currents exercise a considerable effect, so that isolated peaks have, as a rule, a comparatively rough climate.

b. Presence of Extensive Sheets of Water.

Owing to a difference of temperature, and the consequent exchange of air between dry land and sheets of water, the latter cause the climate of the former to be more equable, the temperature being lower during the day and higher during the night. It is for this reason

that the longitude of a locality, by affecting its distance from the ocean, may influence the climate.

c. Aspect and Gradient.

The angle at which the sun's rays strike the soil depends on the aspect of the locality, hence aspects between south-east and south-west are the warmest, and those between north-east and north-west the coldest. The degree of the gradient further modifies this effect.

The aspect affects the temperature also in exposing a locality to air currents, or protecting it against them. This effect may be favourable or unfavourable according to the nature of the air currents.

d. Presence or Absence of Forest Vegetation.

Localities, which are bare of vegetation, are struck by the full force of the sun's rays, causing the temperature at the surface of the soil to rise to the highest possible degree. At the same time, air currents sweep unimpeded over such localities, causing a rapid change of the atmosphere.

On localities covered with a crowded crop of forest vegetation the sun's rays strike the crowns of the trees; the heat which becomes free at some height above the ground, penetrates only slowly through the leaf canopy to the layer of air below it and thence to the soil. During the night again the leaf canopy prevents, or at any rate reduces, radiation. It follows that the air in forests is cooler during the day and warmer during the night, than the air on bare localities. This effect is intensified by the fact that the foliage of the trees impedes the force of air currents.

Direct observations have established the following facts:—

(1.) The climate of wooded countries is more equable than that of open countries.

(2.) The mean temperature of soil and air in wooded countries is somewhat lower than that of soil and air in bare countries. This reduction of temperature would ordinarily act beneficially in warm southern countries, while it may become injurious in cold northern countries where the temperature is already lower than is desirable.

(3.) The greatest difference occurs in summer, next in spring, then in autumn, and it is very small in winter. It follows that in forests the commencement of vegetation in spring is retarded. This may be beneficial in preventing damage by spring frosts, limiting the formation of inferior spring wood, etc.; on the other hand it shortens the growing season, and delays the sprouting of seeds in spring.

Heat is the most powerful agency in the distribution of the plants on the earth; the species change with increasing latitude, elevation, and other influences which govern the temperature. This applies to forest trees as well as to other plants.

Attempts have been made to ascertain the *absolute* sum of heat required annually by the more important forest trees, which have been enumerated in the introduction of this Part, but so far the data which have been obtained are not of much practical bearing upon Sylviculture. Moreover, it is beyond doubt, that the mean temperature is of much less importance to forest trees than the extremes of temperature which occur in a particular locality, more especially during the growing season.

Something more definite is known of the *relative* heat requirements of the several species. According to Gayer * this is as follows:—

It is greatest in: Elm, Sweet Chestnut, English (or pedunculate) Oak, Black Pine.
Somewhat smaller in: Silver Fir, Beech, Weymouth Pine, Sessile Oak, Scotch Pine.
Less again in: Birch, Maple, Sycamore, Ash, Alder, Spruce.
Least in: Larch, Cembran Pine, Mountain Pine.

The different heat requirements produce many phenomena of interest to the forester, of which the following may be mentioned:—

(1.) On the same latitude the several species are, if left to natural selection, found at different elevations. While the Cembran Pine finds full development near the upper limit of tree vegetation (up to 7000 feet in the Alps), the Larch and next the Spruce prefer a somewhat lower zone; lower again appear Beech and Silver Fir, while the Scotch Pine and the Oak flourish in the low lands.

(2.) A species which prefers a certain altitude in one locality, will descend towards the level of the sea with increasing latitude, or ascend with decreasing latitude.

(3.) At the same altitude, the more heat-requiring species will seek the warmer southern aspects, and the less heat-requiring species the cooler northern ones.

* "Der Waldbau," by Dr. K. Gayer, 1882.

(4.) A species which is naturally found on a northern aspect at a low elevation, will seek a southern aspect at a higher altitude.

It must not, however, be overlooked, that the actual distribution is affected by many other influences besides heat, and that the above theories are only of an abstract nature.

The effect of *frost* on the various species is intimately connected with their heat requirements. Trees suffer, as a rule, little from winter frosts within the region of their natural distribution, but frost which occurs during the growing season may do considerable damage, especially during spring (spring, or late frosts), immediately after the tender leaves and shoots have been put forth, and during autumn (autumn, or early frosts), before the newly-formed wood had time to ripen. Many influences and circumstances contribute towards the occurrence of late and early frosts. Sometimes they are caused *locally*, especially in low lying or confined localities in consequence of excessive radiation or evaporation and absence of air currents, in other cases they are due to cold winds. The several species vary much in their bearing towards late and early frosts; in a general way the following classification will hold good:—

Most subject to late and early frosts are: Ash, Acacia, Sweet Chestnut, Beech.

Somewhat less: Oak, Silver Fir, Maple, Sycamore, Spruce, Alder.

Least: Hornbeam, Elm, Birch, Larch, Aspen, Scotch Pine.

The degree of damage depends, apart from the severity of the frost, on the condition of the leaves and young wood, the general health and vigour of the plants, and whether they have been suddenly or gradually deprived of shelter.

2. *Light.*

The earth receives light from the sun, the source whence heat is supplied. With the exception of a few low forms, such as truffles, all plants require light to enable them to live and grow, as soon as the available reserve materials have been consumed. Without light Carbon Dioxide cannot be decomposed.

During the process of germination light is not required, because the germ is developed by means of substances deposited in the seed. Similarly, the first starting of vegetation in spring can take place with a small amount of light, because it is done by means of reserve materials deposited in certain parts of the plant. As soon as these substances, both in germination and awakening of vegetation in spring, have been consumed, light becomes absolutely necessary for the preparation of new growing sap out of Carbon Dioxide, Water, etc. The preparation of this material is accompanied by the exhalation of Oxygen, the result of the decomposition of Carbon Dioxide.

All trees, then, require light for their proper development, but the quantity has its upper and lower limit. Not only too little light but also too much light, can interfere with the phenomena of growth. Between the maximum and minimum a degree exists which corresponds with the most favourable development, and which

represents the normal light requirement of a species. Regarding the absolute quantity of light required by the several species little is known at present, but much experience has been collected which demonstrates the relative light requirements of many species. On the whole it is known that certain species cannot thrive unless they enjoy a large measure of light throughout life, while others will bear a certain amount of shade. Accordingly, the former are called "*light demanding*," and the latter *shade bearing* species. In a general way it may be said, that trees with a dense crown are shade bearing, and those with a thin crown light demanding, though the light requirement does not always stand exactly in inverse proportion to the density of the crown.

Attention must here be drawn to the fact, that some species, which are shade bearing, require a certain amount of shelter, or protection, during early youth; they have therefore been called "shade demanding." Such a definition is, however, misleading, as these plants require protection against heat and cold, and not against light as such. In young plants of Beech and Silver Fir, for instance, the evaporation frequently reaches such a high degree, if not sheltered, that they lose water quicker than they can take it up from the soil, in other words, they must die. Hence they require either a thorough wetting of the soil, or shelter. In the former case more water is available, and in the latter the temperature, and thereby the evaporation, is reduced.

By summing up the available experience of the light requirement of a number of species, scales have been prepared by various authors, which, though agreeing

on the main points, differ somewhat in details. The following scale is that given by Gayer; it begins with the most light demanding species and finishes with the most shade bearing:—

(1.) Larch, Birch.
(2.) Scotch Pine, Aspen, Willow.
(3.) Oak, Ash, Sweet Chestnut, Mountain Pine.
(4.) Elm, Common Alder, Black Pine.
(5.) White Alder, *Lime, Weymouth Pine,* Maple, Sycamore.
(6.) Spruce, Hornbeam.
(7.) Beech.
(8.) Silver Fir.
(9.) Yew.

Lime and Weymouth Pine stand in the centre of this scale; the species above them are considered light demanding, and those below shade bearing, the degree in each case depending on the distance from the centre line.

The above scale represents only general averages. In reality the degree of light requirement is subject to considerable modifications caused by the peculiarities of each locality. Generally, all species bear more shade on good fresh soil than on poor dry ground, a fact which is always indicated by the density of the crown. The Scotch Pine, for instance, grown in fresh soils near the sea-coast looks quite different from the same tree seen in continental countries, and stands considerably more shade than the latter.

The length of the growing season also influences the degree to which a tree will stand shade. A certain

total quantity of light is required to complete the annual cycle of development, hence a more energetic effect of light is wanted in localities with a short growing season, such as high elevations or high latitudes. A species which stands a certain amount of shade at the level of the sea and in a southern climate, may become highly light demanding at a considerable elevation, or in a northern climate. Again, in foggy air, under a usually covered sky, or on northern aspects, the same species stands less shade than in usually clear air, under a sunny sky, or on southern aspects. In this respect it must be remembered that the actual intensity of the light is somewhat greater in high mountains than in low lands.

The health of the trees is also of importance. Strong healthy plants with a good root system stand more shade, and for a longer period, than weak plants.

Light and shade in relation to tree growth are of the greatest importance in practical Sylviculture, especially in the regeneration and tending of woods, the composition of mixed woods, etc. In each of these cases the light requirement of the species must be fully considered, or serious mistakes may be made. The most important period in this respect is early youth, because at that time several species require some shelter, either against heat or frost. If that shelter, on the other hand, is excessive the young trees may be permanently injured or even die. When a plant has stood in shade for some time, the activity of its leaves has been reduced, and it takes some time, after the removal of the shelter, before the increased light produces increased assimilation and visible activity, because fresh organs fitted for the altered conditions, must be pro-

duced. In all such cases it is best to remove the cover gradually and not all at once. If the plant has stood in shade for a considerable period it may be no longer capable of developing into a tree of normal size. As long as numerous strong buds are found, especially near the top, this is not to be feared, but the recovery of plants with a few miserable buds may be considered as hopeless.

3. *Moisture.*

The first question for consideration is, whether moisture in the air is directly necessary or beneficial to plant life. The investigation of this problem meets with great difficulty, because it is often difficult to separate the effect of air moisture from that of soil moisture. As a matter of fact only meagre data are available, as far as trees are concerned. It is known that some species, such as Spruce, Alder, Maple, Ash, and next to these, Silver Fir, Beech, and Birch, thrive generally better in moist than in dry air. It is also a fact, that Spruce appears naturally over extensive areas in high situations and along the sea shores of Northern Europe, that is to say, in localities with a comparatively moist air, while it thrives but indifferently in continental situations with a dry air. The Scotch Pine, on the other hand, appears over extensive tracts in continental dry climates, and at the same time it flourishes in the moist insular climate of Great Britain.

Although further investigation is necessary to show whether trees take up moisture through their organs above ground, the atmospheric moisture is of the highest importance, for the following two reasons :—

(*a.*) It governs the degree of evaporation from the trees; and

(*b.*) It supplies the soil with water, whence it is taken up by the roots of the trees.

Apart from the temperature, the degree of evaporation depends on the degree of saturation of the air; hence relatively dry air causes rapid evaporation, while the latter ceases as soon as the air becomes saturated. The degree of evaporation, in its turn, governs the rapidity with which fresh water laden with raw materials is taken up by the roots.

The soil receives water from the atmosphere in the shape of precipitations, as dew, rain, snow, hail, and a certain amount by means of its hygroscopic nature. The quantities differ enormously in different climates and localities, from almost nothing to 600 inches a year. Precipitation cannot take place unless the air becomes saturated. The phenomena which favour an increase in the relative humidity, and thereby induce saturation, are active evaporation and a reduction of temperature. On the one hand, evaporation causes a reduction of temperature, and on the other hand, a falling temperature reduces the degree of evaporation; the result is, that saturation and precipitation occur only locally.

As a general rule a low temperature means a high degree of relative humidity; hence the latter is greater in winter than in summer; greater at high elevations than in low lands; greater in the vicinity of extensive sheets of water than in continental countries; greater in forest countries than in bare tracts.

Direct observations have shown, that the relative

humidity of forest air is greater than that of open air, the difference amounting in Central Europe to as much as 10 per cent. during summer, and about half that amount in winter. The practical value of this fact in Sylviculture is, that radiation of heat is much slower in moist than in dry air; hence the danger of late and early frosts is smaller in the former than in the latter.

4. *Air Currents.*

The atmosphere is, practically, in constant motion. The principal cause of this is the uneven heating of the earth by the sun. The heat, which becomes free on or near the surface of the earth, warms the adjoining air and causes it to rise, its place being taken by colder air from other parts of the earth. The ascending air, after cooling, sinks again in its turn. In this manner a circular motion exists between the equator and the poles. Owing to a combination of these currents with the motion of the earth, modified wind directions are produced. The prevailing wind directions on the northern hemisphere are, therefore, from the south-west and the north-east, according as to whether the original current started from the tropics or the polar region.

A second cause of wind currents, especially of storms or gales, is the sudden condensation of considerable quantities of aqueous vapour, which forces air to rush from all sides into the space of reduced pressure.

Air currents are of paramount importance to all organic life on the earth, because they produce a thorough mixture of the constituents of the atmosphere. Without them, the firm land would soon lose all moisture. The motion of the atmosphere ensures a proper

distribution of moisture, Carbon Dioxide, Oxygen, and Nitrogen over the earth.

Air currents injuriously affect forest trees principally in two ways:

(*a.*) By unfavourably modifying the temperature and moisture of a locality; and
(*b.*) By injuring, breaking, bending, or overturning them.

Dry winds frequently reduce the moisture of a locality to a dangerous degree; moist and cold winds may reduce the temperature, and thus interfere with the healthy growth of the trees. Strong winds may break the leading shoots or side branches, cause trees to assume a curved shape, or even throw single trees and whole woods to the ground.

Section III.—Soil.

It has already been stated that plants, and more especially trees, require a certain layer of soil, into which their roots penetrate, and which provides them with nourishment and the means of stability. Wherever this layer of soil is deep enough to meet the above requirements, the subsoil is only of indirect importance, but in the case of shallow soils the subsoil has, as a rule, to undertake part of the ordinary functions of the soil. Under any circumstances, the subsoil furnishes the materials from which the mineral parts of the soil are principally derived. Hence, in speaking of the soil, the subsoil is more or less included.

1. *Origin of Soil.*

All soil is originally the result of the decomposition of the rocks of the earth, with the addition of certain organic substances. In some cases the soil now overlies the rock from which it has been derived, in others it has been carried away by violent convulsions, or the action of water and air currents, and deposited again in other places. In the one case it is called "*indigenous,*" and in the other "*exotic*" soil. The latter can generally be brought under one of the following three categories:—

a. Ante-Diluvial Soil,

Consisting generally of layers of clay, marl, and sand, imbedded between masses of rocks, here and there forming the uppermost portion of the earth's crust.

b. Diluvial Soil,

It is distinguished by a low degree of cohesion amongst the several parts, consisting of accumulations of sand, loam, clay, marl, various pieces of rock, etc. It is found in all extensive plains, river basins, and the larger valleys of mountain districts. In the majority of cases it formed the bottom of former seas.

c. Alluvial Soil,

Formed by deposits near the sea-coast, at the mouth of rivers, by moving water and lakes inland, as well as by the action of air currents. This process is proceeding at the present day.

2. *Formation of Indigenous Soil.*

The formation of soil is due to a variety of agencies, which are either of a mechanical, chemical, or organic nature.

a. Mechanical Agencies.

Amongst these, heat takes the foremost place. The heating of rocks produces an unequal strain and pressure, which cause them to burst in various directions. Then, if water penetrates into the interstices and freezes, it forces the particles asunder, thus further breaking up the rock. Water is also a powerful agency, owing to its dissolving action.

b. Chemical Agencies.

When Oxygen, Carbon Dioxide, and water come into contact with the rock, they form chemical combinations with its elements. The Oxygen acts especially on the metals, forming, by the addition of water, hydrates of metallic oxides. This process, accompanied by an increase of volume, destroys the previous cohesion of the rock. The Carbon Dioxide, combined with water, penetrates into the rock and carries off dissolved Lime, Magnesia, Potash, and Soda. The water acts by forming hydrates, which cause the solution of various constituents of the rock.

c. Organic Agencies.

When mechanical and chemical action have commenced the decomposition of the rock, organic action

sets in. First lichens, then mosses, appear on the surface of the rock, which further accelerate decomposition, by keeping the surface moist. Next, the roots of these plants penetrate into the finest fissures and assist mechanical action. In this manner a soil is gradually formed, which consists of fragments of rock and remnants of dead plants, suitable for the support of more highly organized plants, such as grasses and herbs; these are followed by shrubs and trees, which penetrate with their roots deeper and deeper into the rents and fissures of the rock, and further accelerate decomposition.

When this process has gone on for a sufficient length of time, the outer part of the earth's crust consists of a layer of varying depth, which, commencing from below, changes gradually from the solid rock into broken rock, or brash, then into smaller pieces of rock, or subsoil, and ultimately into the formed or surface soil.

At first sight it would appear, that the composition and quality of the soil depend on the composition of the original rock, out of which it has been formed. This is, on closer investigation, found to be the case to only a limited extent, because, in the first place, certain important substances, such as Potash, Magnesia, Lime, are carried away and lost during the process of decomposition; secondly, organic substances are added; and thirdly, the fertility of the soil depends not only on its chemical composition, but also, and often chiefly so, on its physical qualities. All that can be said is, that certain kinds of rock yield ordinarily a soil of a certain description, but subject to modifications, which depend on the peculiarities of each case. On the whole, the

attempt to estimate the quality of a soil by its geological origin has almost invariably failed, since the same rock may produce soil of varying chemical composition and physical qualities.

3. *Composition of Soil.*

Soil consists generally of the following substances:—

(A.) Mineral matter, taken from the decomposed rock, or carried to the area by water and air currents.

(B.) Organic matter, being remnants of vegetables and animals.

(C.) Water, partly fluid, partly in the shape of vapour.

(D.) Gases, such as air, Carbon Dioxide, Ammonia.

A. *Mineral Substances in the Soil.*

The mineral substances form, in the majority of cases, the greater part of the soil; they may be arranged in the following four groups:—

(*a.*) Earths.
(*b.*) Salts.
(*c.*) Acids.
(*d.*) Metals.

a. Earths.

Silica, Alumina, Lime, and, next to these, Magnesia are the earths which occur most frequently in soil.

Silica is represented chiefly in *Sands.*

Silica combined with Alumina forms *Clay.*

Clay with Sand forms *Loam.*

Lime appears principally as Calcium Carbonate in lime and chalk soils, but also as Calcium Sulphate in Gypsum.

Magnesia is most frequent in Dolomite, though smaller quantities are found in most other soils.

b. Salts.

The most important Salts are:—

Potassium Carbonate (Potash).
Sodium Carbonate (Soda).
Sodium Chloride (Common Salt).
Carbonates, Sulphates and Phosphates of Iron and Manganese.

The quantity of salts in the soil does not, as a rule, exceed one-half per cent., and rarely one per cent. Larger quantities appear only in certain localities, such as salt plains, in the vicinity of the sea-coast or salt springs, and in some peaty and swampy soils.

Potassium Carbonate is of importance, as forest trees require a fair amount of it. Sodium Carbonate in moderate quantities acts also favourably. Sodium Chloride only acts favourably if present in small quantities. Salts of Iron often act injuriously.

c. Acids.

Carbon Dioxide and Humic Acid are the two free acids which generally appear in soils. Other free acids, if they appear at all, do so only temporarily, until they enter into combination with a base.

d. Metals.

Of metals, only Iron is of importance in Sylviculture.

It appears as Ferrous Oxide and as Ferric Oxide. The former is believed to be injurious to plant life. Ferric Oxide may be mixed with soils, and unless the quantity exceeds 10 per cent., it does not act injuriously; on the contrary, most fertile soils contain a certain quantity of it.

B. *Organic Matter, or Humus.*

Under Humus is understood in Sylviculture all organic matter which in contact with the soil is gradually decomposed, and forms in mixture with the upper layer of mineral substances, the mould or black earth of the forest. The sources of humus are the annual fall of leaves and twigs (or even whole trees) and dead plants.

The continuous decomposition of humus furnishes several important products. In the first place the soil receives all the mineral matter contained in the humus (ashes); secondly, a large quantity of Carbon Dioxide is produced which accelerates the decomposition of the mineral part of the soil. Finally, Humic Acid renders many important substances, such as Potash, Soda, Magnesia, Lime, etc., soluble in water, so that they become available for the plant.

There are, however, different kinds of humus:—*Mild humus*, or *forest humus* is formed, if air and water act in proper proportion upon fallen leaves, moss, etc. *Dry mould* is formed by the action of an excessive supply of air on certain plants, such as heather. *Acid humus* is the result of the decomposition, if an excess of moisture and a deficiency of air are present. Only mild forest humus acts altogether favourably upon forest vegetation.

C. *Water.*

Water is the most important component part of the soil, as plant life is impossible without a certain quantity of moisture. It affects vegetation principally in the following manner:—

(*a.*) It assists in the decomposition of the rocks.

(*b.*) It assists in the formation of humus, and regulates both the admission of air into the soil and its temperature.

(*c.*) It is a nourishing substance.

(*d.*) It is a chief agent in the process of nourishing and shaping the plant. More especially it carries all mineral substances from the soil into the roots.

However favourably a certain degree of moisture in the soil may act, an excess of water is always injurious; it reduces the activity of the soil (by driving out air), lowers the temperature, increases danger from frost, and is liable to render the soil acid.

The soil receives water from one or more of the following sources:—

(1.) From the atmosphere, as dew, rain, snow, hail, or as vapour condensed by the action of the soil.

(2.) From ground water resting in the subsoil.

(3.) From inundations, whether natural or artificial.

Water derived from the atmosphere acts most favourably, provided the supply is suitably distributed over the different seasons of the year, and the soil is capable of retaining moisture sufficiently long during dry weather. Where these conditions are wanting ground water is

likely to act more favourably, because it produces a more even degree of moisture in the upper layers of the soil. Natural inundation water is, in many cases, objectionable, because it renders the soil too wet at one time, and too dry at others. Artificial inundation, or irrigation, produces most favourable results, but it is generally very expensive.

D. *Gases.*

The gases, such as air, Carbon Dioxide and Ammonia, have been dealt with in Section I. of this chapter. It is only necessary to add, that the contents of air in the soil move within wide limits, and that the contents of Carbon Dioxide and Ammonia depend on the quantity of organic matter in the soil, and the rate at which its decomposition proceeds.

4. *Physical Qualities of the Soil.*

The principal physical qualities of importance in Sylviculture are the following:—

a. Consistency,

Or binding power, the cohesion between the different particles of the soil. It depends on the chemical composition of the different parts, the degree of division, and the quantity of moisture in the soil. Generally, it is greatest in clay and smallest in sand.

b. Shrinking,

Or the reduction of the volume of the soil under the process of drying. It causes the soil to crack, followed by the exposure of the roots. Heavy soils crack more than light soils.

c. Capacity to hold Water.

It is generally proportionate to the percentage of fine earth and humus in the soil.

d. Hygroscopicity,

Or the capacity of the soil to attract and condense aqueous vapour from the atmosphere. It depends on the degree of division of the particles, and on the temperature. The finer the division, the greater the hygroscopicity; more vapour is condensed at a low than at a high temperature. Soils rich in humus show the greatest hygroscopicity, next clays, then loam, then lime soils, and it is smallest in sands.

e. Tenacity of retaining Moisture,

Is greatest in clay soils, middling in lime soils; sand loses moisture most quickly.

f. Permeability,

Or the capacity to let water pass through is greatest in sands, especially if of a coarse grain, and smallest in clay. Humus soil approaches clay, while lime and loam soils stand about half way between the two extremes. Stiff clays are liable to be altogether impermeable; in many cases the clay is gradually carried into the subsoil, where it forms an impermeable layer.

g. The Power to retain the Salts dissolved in Water,

Depends on the proportion of fine earth in the soil.

h. The Capacity to become Heated,

Is greatest in sands, and smallest in clay. Lime soils

approach sand, loam approaches clay. Sand and lime soils are called hot soils, while clay is called a cold soil.

Depth intensifies the effect of the various physical qualities. A depth of 4 feet may be considered as sufficient for any of the species enumerated in the Introduction, and many can do with considerably less. Where a sufficient depth of soil is not available, the direct assistance of the subsoil is called in, especially its degree of permeability. The depth depends chiefly upon the nature of the rock and soil, the stratification of the rock, the situation, and the general shape of the surface. The nature of the rock governs the rate at which it is decomposed, and the rock may, either in itself or assisted by the soil, be more or less permeable. An impermeable subsoil is all the more injurious the nearer it is to the surface, because it makes the surface soil too wet and cold at one time, and too dry and hot at others, apart from the fact that the roots may not find sufficient room for spreading, or that the conditions of stability may be absent.

A vertical stratification and a much crumpled state of the rock act most favourably upon the movement of water in the soil and the penetration of the roots; a horizontal stratification, if unaccompanied by crumpling, is generally the least favourable form. Low lands have ordinarily deeper soils than high lands. On steep slopes the soil is liable to be washed away, while it is collected in valleys.

All physical qualities are of special importance through their action upon moisture. In this respect the chemical composition of the soil is of less importance than the

degree of division of the particles, whether the latter are fine or coarse grained. It is for this reason that sand and clay represent, ordinarily, the extremes. If sand were as finely divided as clay, it would show the same bearing towards moisture as the latter.

5. *Classification of Soils.*

For the purposes of Sylviculture, soils may be classified either according to their chemical composition or according to one or other of the physical qualities.

a. Classification according to Chemical Composition.

It is, of course, out of the question to attempt a classification according to all component substances, nor is it necessary, because the importance of the four substances, Sand, Clay, Lime, and Humus, outweighs that of all other substances so much, that the latter need not be taken into account in this place.

The subjoined table gives the composition of the six principal classes of soils (according to Church):—

Name of Soil	Percentage of				Remarks
	Clay	Calcium Carbonate	Sand.	Humus of Organic Matter	
Clay Soil	over 40	under 5	under 30	5—10	Traces of Ferric Oxide and Bituminous Matter.
Loam	over 30	under 5	60—70	5—10	Coloured Hydrated Ferric Oxide
Marl	over 30	5—10	under 50	5—10	Frequently some Ferric Oxide
Calcareous Soil	under 10	over 10	50—70	5—10	
Sand	under 10	under 5	over 80	5—10	
Humus Soil	under 10	under 5	under 50	over 20	

Soils of subordinate importance are:—

Dolomite, a chalky loam with much Magnesium Carbonate.

Gypsum, a soil which is rich is Calcium Sulphate.

Salt soil, which contains an excessive percentage of salts, especially Sodium Chloride.

Ferrugineous soil, which contains an excessive proportion of Ferric Oxide.

According to the preponderance of one or other of the principal ingredients, numerous subdivisions have been made, such as sandy, chalky, or marly clays; loamy sand, sandy loam, marly sand, sandy marl, etc.

Generally, the clay, loam, and lime soils are minerally strong soils, while the sandy soils are less strong. Humus soil may be real humus soil or peat soil; the former acts very favourably upon tree growth, the latter unfavourably.

Soils may also be classified according to the rapidity, with which the Humus is decomposed, as:—

Very Active Soils: Such as dry porous sand and lime soils, in which the decomposition of humus is excessively quick.

Active Soils: Such as moderately moist loamy sand, sandy loam, loamy marl, in which the decomposition of humus proceeds at a rate favourable for growth, without actually exhausting the supply of organic matter.

Moderately active Soil: Such as stiff clay, wet soil, heather soil, where the decomposition is too slow for a healthy development of most plants.

Inactive Soil: Such as peat soil, moving sand, etc., in which, either from excess of moisture or absence of humus and rest, little or no decomposition takes place.

b. Classification according to Physical Qualities.

Of the various physical qualities the degrees of consistency and of moisture are of special importance in Sylviculture. According to consistency soils may be classified in the following manner:—

Light Soils: All soils which contain much coarse-grained sand or much humus.

Loose Soils: Such as peat and moor soils, which are elastic and swell during rainy weather; they are also much lifted by frost.

Binding Soils: Soils of middling cohesion, such as fine-grained loamy sands, coarser-grained sandy loams, lime soils, especially marl.

Heavy Soils: Such as fine-grained loam, clay with coarse sand.

Stiff Soils: Such as clay with a limited quantity of fine-grained sand.

In classifying soils according to the degree of moisture, a distinction must be made between the absolute degree of moisture, and the condition of the soil during the growing season, as set forth in the following arrangement:—

Wet Soil: Water flows from it without the application of pressure.—Even in summer water runs off in drops on the application of pressure.

Moist Soil: On pressure being applied, water falls in drops.—During summer the soil does not become dry beyond one inch below the surface.

Fresh Soil: Leaves traces of moisture on the palm of the hand on being pressed.—During summer it

does not become dry beyond six inches below the surface.

Dry Soil: Has lost the dark colour due to the presence of moisture, but does not fall to dust on being broken.—In summer it becomes dry to a depth of 12 inches within a week after a good soaking rain.

Arid Soil: Falls to dust on being broken.—In summer it dries up to a depth of more than 12 inches within a few days after a good soaking rain.

Section IV.—Effect of the Soil upon Forest Vegetation.

In estimating the effect which differently constituted soils have upon forest vegetation, and more especially upon tree growth, the forester is guided by the demands made by the trees upon the soil. Ordinarily the soil should provide the tree with:—

(*a.*) Stability.
(*b.*) Space for a suitable spreading of the root system.
(*c.*) Moisture, in suitable quantities at all times.
(*d.*) Nourishing substances, in sufficient quantities and in a condition suitable for absorption by the roots.

Any soil which meets these requirements is fertile for Sylvicultural purposes, and experience has shown, that fertile forest soil must show the following qualities:—

(1.) A sufficient depth.
(2.) A suitable degree of porosity.
(3.) A suitable degree of moisture; and,
(4.) A suitable chemical composition.

1. *Sufficient Depth.*

The depth is measured by the thickness of the layer of soil, and of that portion of the subsoil, which can be penetrated by the roots. In due proportion to depth are the space available for the root system, the store of nourishing substances, the stability of the trees, and the state of moisture in the soil.

The root system differs considerably in the several species; some develop a tap root, which is maintained for a longer or shorter period, such as Oak, Elm, Scotch Pine, Silver Fir, Maple, Sycamore, Ash, Lime, Larch; others have strong side roots, which send down deep-going rootlets, such as Alder; others again go to a moderate depth, as Beech, Hornbeam, Aspen and Birch; finally some spread altogether near the surface, such as Spruce. The nature, composition, and degree of moisture of the soil modify the root system to some extent, which in young trees is frequently different from that in older trees.

On the whole, certain species thrive well only in deep soil, while others can subsist in shallow soil, though they prefer deep soil. The best indicator of the depth of soil is the height growth. A sufficient depth produces full height growth; with deficiency of depth, the height growth falls off.

Hess * classifies the trees as follows, in respect of their demands for depth of soil:—

Species which are satisfied with shallow soils: Spruce, Mountain Pine, Birch, Aspen, Mountain Ash.

* Encyklopadie and Methodologie der Forstwissenschaft, by Dr. Richard Hess, 1888.

Species which require middling depth: Black Pine, Weymouth Pine, Beech, Hornbeam, Black Poplar, Tree Willows, Alder, Horse Chestnut.

Species which require greater depth: Scotch Pine, Cembran Pine, Elm, Maple, Sycamore, White Poplar.

Species which require greatest depth: Silver Fir, Larch, Ash, Lime, Sweet Chestnut, and especially Oak.

At the same time, the roots of these species go rarely to a depth of 4 feet below the surface, unless they do not find sufficient moisture in the upper layers of the soil.

2. *A suitable degree of Porosity.*

Neither too firm nor too loose soils are favourable for tree growth. Too firm soils make the penetration of the roots difficult, if not altogether impossible, prevent the admission of the necessary air, interfere with the movement of water, and incline towards swampiness, accompanied by increased danger from frost, and by strong shrinking and bursting in summer. Too loose soils endanger the stability of the trees, are liable to be carried away by water or wind, suffer from too rapid drying and too rapid decomposition of the humus, and the plants growing in it are subject to frost lifting. The best soils are of middling consistency, such as loam and lime soils with a good layer of humus.

3. *A suitable degree of Moisture.*

Under a suitable degree of moisture is here understood that degree which corresponds with the natural requirement of any particular species, which it is desired to grow. The more uninterruptedly that degree

is maintained throughout the growing season, the more favourable will be the development of the tree.

Apart from climate and subsoil, the condition of the soil itself, its depth, porosity, the nature and proportion of the component parts, affect the degree of moisture. The forester can do much, either to preserve the moisture in the soil by excluding or reducing the agencies which consume moisture, or, if moisture exists to excess, by accelerating its consumption.

The absolute quantity of moisture required annually by each species is not yet known, but experience has shown, that a fresh soil with, as far as practicable, an even and constant degree of moisture suits most of the species enumerated above. For the rest, Hess classifies them as follows:

Most moisture in the soil demand: Common Alder; next to this Ash, most Poplars and Willows.
Moist soil like: Cembran Pine, Weymouth Pine, Hornbeam, Elm, Lime, Mountain Ash.
Fresh soil like: Silver Fir, Spruce, Larch, Beech, Oak, Maple, Sycamore, Sweet Chestnut, White Alder.
On dry soil thrive: Scotch Pine, Black Pine, Birch, Acacia, Aspen.

4. *A suitable Chemical Composition.*

Apart from water and gases, the soil consists of mineral and organic substances. These affect the development of the trees partly by providing nourishment and partly by affecting the physical qualities of the soil. Woody plants take by far the greater portion of their nourishment from the air, more especially carbon, but a

certain portion, including the mineral substances, is derived from the soil. Hence it is of importance to ascertain the actual quantities of such substances in the plant. The contents of mineral substances vary in different parts of the tree; thus wood taken from the stem contains generally less than 1 per cent. of ashes (according to weight), bránches and twigs about 2 per cent., bark alone 2—3 per cent., and leaves and needles from 4—6 per cent. Ebermayer* gives the following quantities of the more important substances, which an average crop takes from the soil, per acre and year:—

TABLE SHOWING THE PRINCIPAL MINERAL SUBSTANCES TAKEN ANNUALLY BY VARIOUS FIELD AND FOREST CROPS FROM AN ACRE OF LAND.

Description of Crop.	Total Quantity of Ashes	K_2O.	CaO.	MgO.	P_2O_5	SO_3.	SiO_2.
	lbs	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Field Crops:							
Rye, Wheat, Barley, Oats .	160	29	14	9	21	1	100
Leguminous Crops, various .	173	44	44	11	27	9	9
Colza	190	62	79	14	43	27	9
Clover (hay)	301	98	107	27	36	11	9
Potatoes	231	107	36	18	32	14	6
Beet	320	164	30	21	28	11	14
Meadow Hay	204	72	44	18	27	11	107
Tobacco	214	55	27	16	16	12	75
Wine	109	84	41	15	21	..	...
Average	215	78	41	17	28	11	37
Crop of Trees, wood and leaves:							
Beech, High Forest . .	191	17	89	15	12	4	66
Silver Fir "	123	16	75	10	10	4	8
Spruce " . . .	138	8	62	8	7	3	15
Scotch Pine " . . .	62	6	21	5	4	2	6
Average	128	11	62	10	8	3	29
Crops of Trees, wood only:							
Beech, High Forest . . .	27	6	13	3·7	2·3	0·3	2·7
Oak " " . . .	24	2·7	18·7	0·9	0·9	0·2	0·4
Silver Fir "	17	6	4	3	1·5	0·9	0·9
Spruce " . . .	20	4	9	2	1·3	0·6	4
Scotch Pine " . . .	13	2	8	1	0·9	0·2	0·4
Birch, High Forest . .	12	2	4	2	1·2	0·1	0·9
Average	19	4	9	2	1·4	0·4	1·3

The data of this table justify the following conclusions:—

* Physiologische Chemie der Pflanzen, Volume I., page 761.

(1.) The substances required by forest trees are, qualitatively, the same as those required by field crops.

(2.) Beech high forest requires for the production of leaves and wood, quantitatively, nearly as much mineral substances, as an average field crop; it requires, more Lime, but much less of the rarer substances, such as Potash and Phosphoric Acid.

(3.) Conifers require smaller quantities, especially Scotch Pine, which is satisfied with about one-fourth of those wanted by Beech.

(4.) For the production of wood alone (excluding the leaves) forest trees require much smaller quantities, than field crops. Thus Beech takes only one-ninth, Scotch Pine about $\frac{1}{18}$th, and the six species enumerated on an average about $\frac{1}{12}$th of the quantity required by field crops. Of the rarer substances, Potash and Phosphoric Acid, trees take, on an average only about $\frac{1}{20}$th of the quantity necessary for field crops.

(5.) Almost any soil can furnish a sufficient quantity of mineral substances for the production of a crop of trees, provided the leaf mould (humus) is not removed, and good soils will continue to do so, even if a certain portion of the humus is taken away. If, however, the removal of leaf mould is carried on annually and for a long period, any but really fertile soils are likely to become exhausted, just as lands, on which field crops are grown, cannot as a rule go on for ever without manuring.

(6.) Poor soils, which are not capable of producing a crop of broad leaved trees, may yet be able to yield a fair return if planted with less exacting Conifers, especially Scotch Pine.

The above conclusions agree with the results of practical experience. It has been found, that the quantity of wood production is not directly proportionate to the quantity of mineral nourishing substances in the soil. Again, woods thrive equally well on soils of the most different geological origin, while great differences exist in the development of one and the same species if grown on soils of the same geological origin. These phenomena are explained by the great importance of the physical qualities of the soil, depth, porosity and a proper degree of moisture. To ensure a favourable condition of the physical qualities should, therefore, be the forester's chief aim, and this he can do best by preserving the humus, especially on middling and poor soils. It increases the depth of the soil, absorbs from the atmosphere considerable quantities of aqueous vapour, Carbon Dioxide and Ammonia; it is capable of holding a large measure of water, which it gradually gives up to the lower layers of the soil; it loosens too firm a soil, and gives somewhat more consistency to a soil which by itself is too porous; finally it moderates the extremes of cold and heat. The poorer a soil the more important is the preservation of the humus, provided it is not acid.

5. *Summary.*

Taking now all the demands which forest trees make on the soil, as a whole, it may be said that all species like a soil which is minerally strong, deep, porous, fresh, warm, and rich in humus, such as a mild loam soil with a good layer of humus. Some species find the necessary conditions more on one class of soil than on another;

for instance, Beech, Ash, Elm, Maple, and Black Pine, like a certain quantity of Lime in the soil, probably less on account of its chemical composition than of the physical qualities which an admixture of Lime produces. Coniferous trees, on the other hand, are more frequently found on loamy and sandy soils.

Though all trees like a good fertile soil, the several species differ considerably as to the minimum of fertility with which they can thrive; that is to say, some are more exacting in their demands than others. In this respect Hess gives the following scale:—

Least exacting are: Black Pine, Scotch Pine, Weymouth Pine, Birch, Poplars, Tree Willows, Mountain Ash, Acacia.

The transition to the next class form: Mountain Pine, White Alder.

Middling exacting are: Spruce, Cembran Pine, Larch, Common Alder, Lime, Osiers, Horse Chestnut, Hazel.

The transition to the next class form: Hornbeam, Maple.

Much exacting are: Silver Fir, Beech, Sessile Oak, Sycamore, Ash, Elm, Sweet Chestnut, and English Oak.

It will be observed that the valuable broad-leaved species are, on the whole, more exacting than the soft broad-leaved species and the Conifers.

Any classification like that given above must, however, be received with some caution; its object is merely to give a general idea of the subject. In practice deviations occur constantly, according to the local conditions under which trees grow.

Section V.—Effect of Forest Vegetation on the Locality.

It has been shown in the previous sections that the condition of the locality governs the growth of forest trees. It is now necessary to look at the effect of forest vegetation on the locality, more especially on two of its factors—humus and moisture. This effect is chiefly produced by the following two agencies :—

(1.) The protection which growing woods afford to the soil and adjoining layers of air ; and

(2.) The humus which is formed by the fall of the leaves, flowers, fruits, etc., and by certain plants which grow under the shelter of the trees.

In well-stocked or crowded woods the crowns of the trees form a thick leaf canopy, or complete cover overhead. If the trees are all of the same age and height, the leaf canopy is at a uniform height above the ground, that height being at first small, but increasing with age. In woods of uneven age the cover is of a somewhat different nature; it consists of groups of crowns at varying distances from the ground. In either case the cover overhead protects the soil and adjoining layers of air against sun and wind; in even aged woods more against sun, and in uneven aged woods more against wind.

Again, the trees shed their leaves, flowers, fruits, and even branchlets, while mosses and other plants, which thrive under the shelter of the leaf canopy, die, thus forming a layer of humus on the soil. Finally the roots of the trees penetrate into the soil and keep it together.

The shelter from above, the humus on the soil, and the roots of the trees together produce certain effects, which may be summarized as follows:—

(1.) The temperature of the soil and the adjoining section of air is lowered during the day and raised during the night; hence the extremes of temperature are moderated, and the climate rendered more equable.

(2.) The mean temperature of the soil and the adjoining air is lowered; the reduction is greatest in summer, next in spring, next in autumn, and it is slight in winter. It is also greater in the soil than in the adjoining section of the air.

(3.) The relative humidity of the air is increased, the evaporation from the soil reduced, and precipitation probably increased.

(4.) Noxious forest weeds are kept in check.

(5.) A favourable degree of moisture in the soil is maintained.

(6.) A steady and suitable progress in the decomposition of the humus is ensured.

(7.) An additional supply of organic matter, taken by the plants from the atmosphere and brought into the soil by the falling leaves, flowers, fruits, and twigs, decaying mosses and other plants, is procured.

(8.) The soil is protected against the mechanical action of water and air currents.

In order to produce these effects in a high degree, it is necessary that the leaf canopy should be dense, so that it not only keeps out sun and air currents, but also yields a heavy fall of leaves for the production of humus. Only certain species of forest trees possess these two qualifications. During youth most species answer, no doubt,

very well; with advancing age, however, the crowns are not only lifted higher and higher from the ground, but most species thin out considerably. The result is, that the leaf canopy becomes more and more interrupted and thinner, followed by a crop of noxious weeds, or too rapid decomposition of the humus, accelerated evaporation of the moisture, and generally a reduction of the fertility of the soil. To prevent such results, the forester must either cut over the wood before the process of thinning-out has proceeded too far, or he must cultivate species which are capable of maintaining a complete cover overhead up to an advanced age.

Amongst the timber trees with which this book deals, Beech, Silver Fir, and Spruce are the three species which, above all others, preserve a complete leaf canopy until, or near to, maturity. These are shade-bearing species. All other species are, with certain modifications, less capable of preserving the factors of the locality; the greater their light requirement and the thinner their crowns, the smaller their capacity in this respect. Those least suitable are Birch, Poplars, Acacia; next Willows, most Pines (with advancing age), Larch, Elm, Maple, Sycamore, Oak, Ash, Alder.

The production of humus from falling leaves is greater in woods consisting of broad-leaved species than in coniferous woods, because the more important broad-leaved species are deciduous and shed the whole of their foliage every year, while, with the exception of Larch, the Conifers are evergreen. The Silver Fir sheds about one-ninth of its foliage annually, Spruce about one-seventh, the Pines about one-third to one-fourth. The production of humus from falling leaves is, generally

speaking, greatest when the rate of height-growth culminates.

The accumulation of humus depends greatly on the rapidity with which the leaves are decomposed, a process which is regulated by the species, degree of cover overhead, and the character of the locality. Generally speaking, needles decompose more slowly than leaves. Of needles, those of the Larch decompose quickest, next perhaps those of Weymouth Pine, Scotch Pine, and Black Pine, last those of Silver Fir and Spruce. Of leaves, those of Ash, Alder, Hornbeam, Lime, and Hazel decompose quickly; more slowly the leaves of Oak, Birch, and Sweet Chestnut. The leaves of Beech stand perhaps half-way, but as Beech woods enjoy a dense shade, their accumulation of humus is much greater than that found in Oak or Birch woods. On chalk and sandy soils the decomposition of the humus is quicker than on loam and clay soils. It is also quicker in warm low lands than in vapoury mountain regions. The most suitable, or normal, time for the process may be put at two to three years, when the most favourable results in respect of quantity and quality of humus are produced.

A few words about each of the more important species will not be out of place here:—

Beech improves the soil in the highest degree, because it has a dense crown and yields a heavy crop of leaves, which decay slowly. Beech woods, if undisturbed, show a thicker layer of humus than woods of any other species.

Hornbeam approaches Beech in this respect, though it does not equal it.

Lime gives good shade and a heavy crop of leaves, but its timber is of such inferior quality that it is not planted for economic purposes.

Sweet Chestnut sheds a heavy crop of leaves, but the leafy canopy is comparatively incomplete, admitting too much sun.

Oak and all other broad-leaved timber trees have too thin a leaf canopy to do justice, generally speaking, to the locality.

Silver Fir and *Spruce* are capable of preserving a dense cover overhead up to an advanced age.

Evergreen Conifers, other than Silver Fir and Spruce, though they may not possess a dense leaf canopy, are often capable of preserving the fertility of the soil for a certain period, because, under their half shade, mosses grow, which protect the soil just as well as a thick layer of leaves. When the Conifers begin to thin out to some extent, the mosses disappear gradually; hence these species should not by themselves be treated under a high rotation. Of the Conifers which are here spoken of, Weymouth Pine, Black Pine, Cembran Pine, and Mountain Pine have a fairly dense leaf canopy, and yield a considerable crop of needles, more especially Weymouth Pine. Scotch Pine has a thinner crown, and a tendency to open out after the age of thirty or forty years, when the moss is liable to disappear and to be replaced by a crop of grass. At the same time the density of the leaf canopy of this tree differs very considerably according to the conditions under which it is grown. The Scotch Pine grown in the moist climate

of England and Scotland gives a much denser cover than when grown in dry continental climates.

Larch provides but a thin leaf canopy in summer, and is leafless in winter. It commences to thin out at an early age; the moss disappears quickly, and the needles decay rapidly, so that the tree is unfit for preserving the fertility of the soil.

The power of preserving the factors of the locality which is peculiar to the several species, governs their adaptability to be raised in pure woods, a subject which will be dealt with in Chapter III. of this book.

Section VI.—Assessment of the Quality of the Locality.

It is the duty of the forester to select that species which is best adapted for cultivation in any particular locality, and in order to attend to this duty successfully, means must be provided by which the quality, or yield capacity, of the locality can be readily ascertained. Various methods have been proposed for this purpose, of which the following two shall be shortly considered here :—

(1.) Assessment according to the several factors of the locality.

(2.) Assessment according to a crop of trees already produced on or near the locality.

Whenever the second method is possible, it should be followed; only in the absence of a forest crop should the first method be adopted.

A third method may be mentioned here. It has been proposed to assess the quality according to the natural appearance of certain plants, which would depend either on the presence in the soil of certain substances, or on a certain condition of the soil. Though this holds good to some extent, the method of assessment is without practical value in Sylviculture, and it need not, therefore, be dealt with in this place.

1. *Assessment of the Locality according to its several Factors.*

The factors of the locality naturally arrange themselves into two groups, those of the climate and those of the soil and subsoil.

As regards climate, it is necessary to ascertain:

(*a.*) The geographical position of the locality, that is to say, the latitude, and in some cases, the longitude.

(*b.*) The local peculiarities of the locality, such as altitude, aspect, slope, surroundings, temperature, moisture in the air, rainfall, exposure to cold or dry winds, susceptibility to late or early frosts, etc.

All these matters have been dealt with in Section II. of this Chapter.

Turning now to the soil, the following points, as indicated in Section III., require attention :—

(*a.*) The depth of the soil.
(*b.*) The degree of porosity.
(*c.*) The degree of moisture peculiar to the soil.
(*d.*) The chemical composition.

A detailed examination of the factors of the soil is a complicated and difficult operation, which it is not intended to describe here. There is, however, a somewhat rough and ready method, which generally suffices for sylvicultural purposes, and which shall be shortly indicated.

The most convenient way of examining the soil is to dig a hole, if possible in a spot which promises to yield average results. On generally level ground the spot should be selected on a uniform part of the area, that is to say, neither in any small depression nor on any slight elevation which may exist. In hilly or mountainous localities, separate holes must be dug on the ridge, the slope, and at the bottom of the valley. The depth of the hole must be at least equal to the depth to which the roots penetrate, that is to say, 3 to 4 feet. Where rock is met at a shorter depth than this, its stratification and general composition should be ascertained, as well as its effect upon the regulation of moisture and the stability of the trees. One side of the hole, at any rate, should be perpendicular, so that the thickness of the successive layers of the soil can be measured in so far as they are indicated by different colour, different degree of cohesion, and other outward signs. The depth to which the soil is coloured dark by humus should be specially noted.

This operation will show whether the soil is sufficiently deep to admit of a proper spreading of the roots, and if not, the examination of the subsoil will indicate how far the latter can make up for the shallowness of the surface soil. The same operation will indicate what effect the depth and nature of the soil has on the degree

of moisture. Next the degree of division, or the nature of the grain of the soil, must be ascertained. This can be done by shaking a sample, if necessary of each successive layer, with about three times its volume of water in a graduated tube, until all parts are thoroughly separated; the tube is then placed in a perpendicular position and watched. As coarse grains settle quicker than fine grains, it follows, that the time compared with the thickness of the deposit indicates the degree of division of the particles. A high degree of division indicates a stiff soil, the presence of coarse grains the reverse, and thus an idea can be formed of the degree of porosity.

If necessary, the capacity to absorb water, to attract it from the subsoil, to retain it, and the hygroscopicity of the soil can be ascertained by special experiments, but in practical Sylviculture they are rarely called for.

The exact composition of the soil can only be ascertained by means of a detailed chemical analysis. In practice the forester can easily acquire the faculty to distinguish between the several constituents in a rough and ready manner. He recognizes: *Clay* by a high degree of cohesion, a fatty feeling, active absorption of water while emitting a clayey smell, slow dissolution in water, slow drying followed by cracking, a grey colour, etc.; *Loam* by a lesser degree of cohesion than in the case of clay, rougher feeling, quicker dissolution in water, and generally a more reddish colour; *Lime* by active effervescence if treated with an acid, porosity, light whitish to greyish-white colour, which is, however, frequently turned red by iron, a rough, but fine-grained feeling, etc.; *Sand* by very slight cohesion, grinding

between the teeth, or hard grainy feeling, immediate dissolution in water and rapid settling down in it, a light, glossy, shiny, yellowish-white colour, often converted into red by iron, into white by lime, into black by humus; *Humus* by its porosity and light weight, peculiar smell like that of fresh garden earth, rapid dissolution in water, which remains dark-coloured for a long time, blackish colour which disappears on roasting; *Iron* by red colouring, etc.

In order to recognize more easily the principal constituents of a soil and their proportion, a sample may be mixed with about twice its volume of water, well stirred until completely dissolved, and then allowed to settle. At the bottom of the glass tube the following deposits will be observed, beginning with the lowest:—

First: The rougher grains of Sand.
Second: The finer grains of Sand.
Third: Lime and the coarser Clay.
Fourth: The finer Clay and particles of Humus.

The thickness of the layers indicates the proportion of each substance.

In spite of the most persevering attempts, experience has shown that the assessment of the locality in the manner indicated above is always subject to grave errors, because the various factors may compensate each other, replace one another, or may be altogether unassessable. To make matters worse, the factors are rarely the same over extensive areas, but change from one spot to another. On the whole, the method which has just been indicated can only serve as a make-shift when no better means of assessment are available, or as

a help in the application of the method now to be described.

2. *Assessment of the Locality according to a Crop of Trees.*

When a locality has already produced a crop of trees, it may be assumed that, unless extraordinary events or irregular treatment have interfered with the development of the trees, the effects of all the factors of the locality have found due expression in such crop, which is therefore the best guide for the assessment of the quality, or yield capacity, of the locality. If, for instance, an acre of ground has produced a total quantity of 5000 cubic feet of wood in the course of 100 years, the quality, or annual yield capacity, is represented by $\frac{5000}{100} = 50$ cubic feet per annum, in other words by the mean annual production.

The applicability of this method depends principally on the following three conditions:—

(*a*.) That the existing wood has grown up under normal conditions; in other words, that no extraordinary disturbing events have occurred which affected the health and development of the crop, as for instance, damage by cattle or deer, insects, fire, theft, removal of litter, faulty treatment, etc.

(*b*.) That the factors of the locality have not undergone any decided change, either for the better or worse, since the existing crop was created; for instance, the stock of humus or the degree of moisture may have been affected by external interference.

(*c*.) That the existing crop is of a sufficient age to

make sure that the factors of the locality have found a thorough expression in the existing crop, since a wood may thrive well up to a certain age and then fall off considerably.

Whenever these conditions exist to a fair extent, the method of assessment is the best which is at the forester's disposal; and in its application he need not restrict himself to a crop actually growing on the area, but he may be guided by one growing on a neighbouring piece of land, provided the general conditions are the same in both cases.

A great quantity of data bearing on the yield capacity of land has, in the course of time, been collected and brought together in so-called "*Yield Tables*," that is to say, tables which indicate the yield which an acre of land may reasonably be expected to give according to whether it belongs to one or the other quality. By way of illustration a table is given below, which indicates the final yield (exclusive of thinning) of Scotch Pine woods in Germany; the localities are classed into five qualities, and the figures present the mean of very numerous measurements.

GROWING STOCK OF SCOTCH PINE WOODS, IN CUBIC FEET PER ACRE.

Age of Wood	Timber and Faggots.					Timber only, 3 Inches at the Thin End and Upwards.				
	Number of Quality or Yield Capacity.					Number of Quality or Yield Capacity				
	I.	II.	III.	IV.	V.	I	II	III	IV.	V.
20	2,330	1 630	1,270	1,040	610	770	70	20		.
30	3,670	2,760	2,140	1,710	1,390	2 210	1,170	830	440	300
40	4 600	3 800	2,900	2,370	1,900	3,570	2,430	1,470	1,290	900
50	5,920	4,740	3,530	2,010	[illegible]	[illegible]	3 940	2,700	2 010	1,490
60	6,750	5,430	4,000	[illegible]	2,670	6 020	[illegible]	3,300	2,610	1,870
70	7,510	5,960	[illegible]	3,730	2,970	[illegible]	[illegible]	[illegible]	3,070	2,240
80	8,140	6,400	4,070	3,990	3,190	7,120	5,720	[illegible]	3,350	2,610
90	8,670	6,760	5,000	4,170	3,300	[illegible]	6,100	4,620	3,530	2,690
100	9,110	7,090	[illegible]	.	..	[illegible]	6,410	4,910	.	.
110	9,500	7,870	5,520	.		8,780	6,670	5,150	.	..
120	9,760	7,640	6,910	.	.	9,030	6,050	5,840	.	

Assuming that a Scotch Pine forest contains, when 60 years old, on a fully stocked acre 4,000 cubic feet of timber and fagots, then the locality on which it grows belongs to the III. quality; if it contained 5,420 cubic feet, it would belong to the II. quality. If the number of cubic feet fell between these two figures, it would be classed as of that quality which it approaches nearest. For instance, if the growing stock came to 5,100 cubic feet, the locality would belong to the II. quality; if 4,500 it would be placed into the III. quality.

How tables of this kind are prepared and used is described in works on Forest Working Plans. Some information on the subject will also be found in a pamphlet published by the author and entitled "Yield Tables for the Scotch Pine." *

* W. H. Allen & Co., Waterloo Place. London, 1888

CHAPTER II.

SHAPE AND DEVELOPMENT OF FOREST TREES.

In dealing with the shape and development of forest trees, it is assumed that the student has already acquired a botanical knowledge of the several species, so that here only their sylvicultural characteristics need be described, more especially the shape peculiar to each species, the height, diameter and volume-growth, the lease of life and the reproductive power.

1. *Shape.*

Different species of trees naturally develop different shapes. Some species, like Spruce, Silver Fir and Larch, have a decided tendency to form a strong stem in preference to the development of the crown. Others, like English Oak, Lime and Sweet Chestnut, develop their crown in preference to the stem. The actual shape depends, however, on a variety of influences, amongst which the following may be mentioned:—

a. Growing Space.

The individual character of a tree can be best recognized if it has grown up in a free position, so that its natural development has not been interfered with. When trees have been reared in this way their shapes can be arranged into the following classification:—

An undivided stem throughout have: Spruce, Silver Fir, Larch, also Weymouth Pine.

Divided in the upper part only are: Scotch Pine, Alder, Beech, Sessile Oak, Black Poplar, Cembran Pine.

Divided somewhat lower down are: Ash, Maple, Sycamore, Elm.

Decidedly branching with a divided stem comparatively low down: English Oak, Lime, Sweet Chestnut, Hornbeam, Mountain Pine.

The shape is considerably altered when the trees are grown in crowded woods, where each enjoys only a limited growing space. In that case all species have a greater tendency to the development of stem than of crown, and this in the same proportion as the species is light demanding, and the growing space reduced. Thus the crown of the Silver Fir covers often the whole of the upper half of the tree, that of Spruce the upper third (and generally a little more), also that of Beech and Hornbeam; the crown of Larch, Scotch Pine, Oak, Birch and Aspen is reduced to the uppermost part of the stem. The effect is, that the more elevated the crown is, the nearer will the shape of the bole approach that of a cylinder, and consequently the more valuable will it be.

b. Age.

All species, when grown in crowded woods, develop during the early part of life a conically shaped crown, but when they approach their full height the crowns differ considerably, so that the following classification applies:—

A conical crown with thin branches have: Spruce, Silver Fir, Larch.

An egg-shaped crown have: Elm, Beech, Maple, Sycamore, Birch, Sessile Oak.

An inverted broom shape, horizontally extended, with strong branches, have: English Oak, Sweet Chestnut, Black Poplar, Lime.

After the height-growth has been completed the crowns of all trees become flat or rounded off, more or less extending in breadth. Only Spruce makes an exception, as the leading shoot continues to grow up to a great age, though very slowly.

The practical conclusion to be drawn from these peculiarities is, that only shade-bearing species, which are satisfied with a limited growing space, are capable of preserving a complete cover up to an advanced age, such as Silver Fir, Spruce, Beech, and also Hornbeam. Much inferior in this respect are Ash, Maple, Sycamore, Scotch Pine and Larch, chiefly because they are light-demanding. If to the demand for light is added a strong tendency to develop branches, then the interruption of the cover occurs early, as in the case of Oak (especially English), Birch, Sweet Chestnut and Alder. This tendency is the more pronounced the less suited the locality is for the species.

c. Soil.

The nature of the soil influences the shape of the trees in the case of all species. Fresh, deep, fertile soils encourage height-growth. Shallow, rocky soils produce

only short stems with a tendency to divide the stem and to develop branches.

d. Situation.

The development of stem decreases with rising elevation, while that of branches increases. At great elevation the shape is reduced to that of a shrub or bush. Similar phenomena are observed on proceeding north, and in localities exposed to cold winds. Trees exposed to continuous strong winds, as near the sea coast, assume often a one-sided shape.

Some species are frequently forked, as Ash, False Acacia, and also Elm. Cembran Pine often shows a candelabra-like shape, especially in stony situations.

2. *Height-Growth.*

The energy of height-growth differs not only according to species, but is also subject to considerable modifications in the case of one and the same species, according to the age of the tree, the locality, method of creation and of treatment.

a. Species.

Amongst the trees of Central Europe, Spruce, Silver Fir, Larch, Weymouth Pine and Scotch Pine attain the *greatest height*; they frequently reach a height of 120 feet and more.

Next come: Oak, Ash, Beech, Lime, Maple, Sycamore; then Elm, Poplar, Birch. These species rarely exceed a height of 110 feet.

Next come: Black Pine, Cembran Pine, Hornbeam, Alder, Willow. They do not, as a rule, exceed 75 feet in height.

b. Age.

The energy of height-growth during the first part of life is of special importance in sylviculture. Generally the light-demanding species are at this time faster growing than the shade-bearing species. Assuming favourable conditions of growth as found in the natural home of each species, they may during youth be arranged as follows,* commencing with the fastest growing kind:—

Birch, Larch.
Aspen, Alder, Maple, Sycamore, Ash, Lime, Elm.
Weymouth Pine.
Scotch Pine.
Black Pine.
Oak, Sweet Chestnut.
Hornbeam.
Beech.
Spruce, Cembran Pine.
Silver Fir.
Yew.

As soon as the first youth, say up to 20 or 30 years, has been passed, a considerable change occurs. Some species, like Larch, and under favourable circumstances also Scotch Pine and Birch, preserve their fast growth until they have completed their principal height-growth. Others, like Cembran Pine and also Hornbeam, remain

* According to Gayer.

slow height-growers throughout life. The majority of species, however, increase their rate of height-growth considerably, and this is specially pronounced in Spruce,

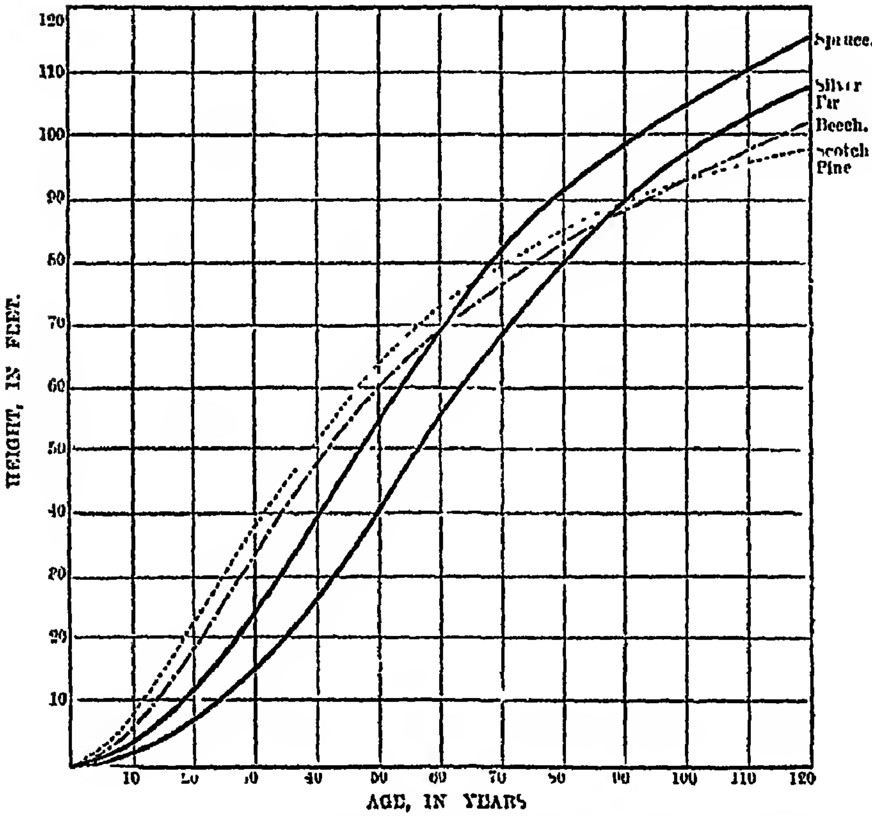


DIAGRAM ILLUSTRATING THE RELATIVE HEIGHT-GROWTH OF SPRUCE, SILVER FIR, BEECH AND SCOTCH PINE; according to the Yield Tables of Baur (Spruce and Beech), Lorey (Silver Fir), and Weisse (Scotch Pine).

Silver Fir, also Beech and Oak, so that they soon reach and surpass trees like Ash, Maple, Sycamore, Aspen, which do not grow at the same rate.

The duration of height-growth in the more advanced periods of age is greatest in those species in which the

development of stem naturally predominates over that of the crown, such as Spruce, Silver Fir and Larch, and these species reach ultimately the greatest height.

Amongst broad-leaved species, Sessile Oak, Elm and Beech preserve their height-growth longest. In the case of the other broad-leaved species, the crown is rounded off at an earlier period, when height-growth ceases.

c. Locality.

The factors of the locality have a decided effect upon height-growth. It has already been pointed out that deep, fresh, fertile soils produce much higher trees, than shallow, dry, rocky soils. Elevation exercises also a considerable influence. It may be said that every species shows its greatest height-growth at that elevation which offers the most favourable climatic conditions for its growth; above that elevation the height-growth decreases, and in many cases also below it. In situations exposed to strong air-currents and other unfavourable influences, height-growth is comparatively small.

d. Methods of Creation and of Treatment.

They affect the height-growth principally on account of their effect upon the establishment and preservation of a complete leaf canopy. The more complete the cover, the better will be the effect upon the height-growth of most broad-leaved species, Scotch and other Pines; it is less pronounced in the case of Silver Fir, Spruce and Larch. In this respect the manner in which thinnings are conducted is of paramount importance, a subject which will be dealt with in Part III. of this Manual.

3. *Diameter-Growth.*

Generally speaking, the increase of the diameter of the stem (or bole) is, in the case of all species, fairly proportionate to the height-growth, that is to say, both height- and diameter-growth are greatest at the same period of life. In the case of light-demanding species the diameter-increment often reaches its maximum between the 20th and 30th year of age, a good increment being maintained up to the 50th or 60th year, when it commences to fall off. Shade-bearing species and Oak reach the maximum diameter-increment later on, but it is also longer maintained, often up to the 90th year, before it commences to fall off to any considerable extent.

Apart from species, the diameter-increment depends on—

(a.) the quality of the locality, and

(b.) the amount of light which the tree receives and can utilize, in other words the extent of the crown, which is governed by the growing space.

Limited space in a crowded wood reduces the diameter-increment, a free position increases it; hence height-growth and diameter-growth demand in most cases opposite conditions. It is the business of the Forester to give the most profitable growing space, in other words to give to the individual trees from time to time sufficient room to encourage diameter-growth, without endangering the progress of the height-growth.

The effects of a great surface of foliage and unimpeded enjoyment of light are very remarkable, when healthy trees, which have been raised in a crowded wood, are gradually given more growing space. Such an opening out can even produce a revival of the diameter-increment, after its maximum has been passed, provided the period of height-growth has not come to an end.

Where both great height and diameter-growth are wanted, it is best to keep the wood crowded during youth, and to give only a moderate growing space to each tree until towards the end of the principal height-growth, when the growing space of each remaining tree should be gradually increased, so as to develop more extended crowns and greater diameter-growth. This is only possible while height-growth is still going on; once that has stopped, the thinning out will not be followed by any appreciable extension of the crowns, which can only be produced by transferring to it the energy of height-growth. The possibility of such a transfer is longest preserved in Silver Fir, Spruce, Larch, Oak, and Beech.

4. *Volume-Growth.*

The increase in volume depends on both height- and diameter-growth, and that method of treatment which promotes each in due proportion, must ultimately yield the largest volume; in other words, woods should be neither too crowded, nor too open. In the one case thin tall trees, and in the other short thick trees, would be produced. The most favourable density of the crop can only be ascertained by accurate statistics. General ex-

perience has shown that the greatest volume is ultimately obtained, if the woods are at first crowded to produce height-growth, and afterwards more open to add diameter-growth.

Apart from these general considerations, a great difference exists in the volume produced by the several species when grown in regular woods; and in this respect some of the more important kinds may, according to the latest investigation, be arranged in the following manner, commencing with that species which produces the greatest average increment, calculated for a prolonged space of time:

Silver Fir.
Spruce.
Larch, Weymouth Pine.
Scotch Pine.
Beech.
Oak.
Ash.
Birch.

Hence, coniferous woods are called fast growing, as compared with woods which consist of broad-leaved species.

The increment laid on by an individual tree does not by itself govern the increment produced per acre, because the latter is represented by the increment per tree, multiplied by the number of trees per acre. For instance, if an acre of ground can hold 100 mature Silver Firs, each of which has a volume of 100 cubic feet, the total volume per acre will be 10,000 cubic feet; if an acre can hold 50 mature Oak trees, each with a volume of 150

cubic feet, the total volume per acre will be only 7,500 cubic feet, or 2,500 cubic feet less than in the case of Silver Fir.

The number of trees which find room on an acre of ground depends chiefly on :—

(a.) The light-requirement of the species; and
(b.) The tendency of the species to develop the crown in preference to the stem.

Hence, an acre stocked with the light-demanding Birch, Ash, or spreading Oak, contains a smaller number of trees and a smaller volume than an acre stocked with Beech. Again, Larch and Scotch Pine woods contain fewer trees and a smaller volume per acre than Silver Fir and Spruce woods. The following data will illustrate this; they give the average growing stock per fully stocked acre at the age of 120 years, in localities of the first quality in each case :—

Silver Fir	=	17,400	cubic	feet	per	acre.
Spruce	=	14,500	,,	,,	,,	,,
Scotch Pine	=	9,780	,,	,,	,,	,,

5. *Duration of Life.*

A great difference exists in the age which the various species attain ultimately. If grown under conditions which are in harmony with their requirements, the Yew lives for more than 1000 years, the Oak comes often near that age, if it does not exceed it; Lime, Elm and Sweet Chestnut reach and surpass an age of 500 years; Beech reaches a similar age under favourable circum-

stances, but ordinarily both Beech and Silver Fir die before that age. A limit of 300 years may be assigned to Ash, Maple, Sycamore, Spruce, Larch, Scotch Pine and Hornbeam; while Aspen, Birch, Alder and Willow live, under ordinary conditions, rarely more than 100 years.

In Forestry the trees are, as a rule, cut over long before they have reached the natural end of their life. Nevertheless many cases occur, where trees have been grown under conditions which are not quite in harmony with their requirements, so that they die, or at any rate fall off in health and growth, long before they would, in the ordinary course, be cut over; hence it is of importance to consider the conditions under which the growth continues to be healthy to an advanced age:—

In the first place, the nourishing organs, crown and roots, must be able to develop normally in accordance with the requirements of the tree at the different periods of age; in other words they must be given at all times the required growing space, without, however, checking their height-growth or interrupting the cover overhead. Unless a tree is provided with a sufficient quantity of organs, it will not be able to overcome successfully internal and external damage which endangers its life. The power of resistance in this respect differs considerably in the various species. It is great in Oak, Lime, Willow, Elm, Yew, Cembran Pine, but small in Alder, Maple, Sycamore, Beech, Spruce.

The second condition of longevity is, that the locality should offer to the tree all it requires for a proper development. On the whole it may be assumed that where a tree is indigenous, it finds all it requires (though this

is not without exceptions). Localities with different factors are liable to be unsuited to the species, either from offering too little or too much in respect of temperature, moisture, contents of nourishing substances in the soil, depth, etc. Either case may be injurious to the development of the tree, and especially to the quality of the timber produced. For instance, Larch and Spruce are naturally fond of a cool climate; by transferring them to the dry and warm air of the low lands, they generally grow much quicker, but they yield inferior timber, are shorter lived, and subject to more dangers, than in their mountain home.

Trees raised in fully stocked compact woods do not live as long as when raised in the open. Moreover, in that case various other important considerations must be taken into account. After having weighed these, the *forester decides on the age limit which is most likely* to realize the objects of management.

What the objects of management are has been indicated in the Introduction of this Part. It will suffice to add here, that they govern the determination of the "*Rotation,*" or the time which elapses between the creation and final cutting over of a wood. Whatever motives may influence the selection of the rotation from a sylvicultural point of view, it must always be remembered, that it should be so fixed under the method of natural regeneration as to admit of a proper regeneration of the wood, whether by seed or coppice shoots; in other words the wood must be cut over while the reproductive power of the species is in an active condition.

6. *Reproductive Power.*

The tendency to reproduce the species manifests itself throughout nature; in fact the energy devoted to reproduction is frequently stronger than that bestowed upon the preservation of life. The forest trees, in obedience to this law, produce seed during a considerable part of their life, and in large quantities.

In Sylviculture, the reproduction of trees and woods is effected in two distinct ways, namely:—

(*a*.) From seed; or

(*b*.) From shoots which spring from the stool, followed, in many cases, by the division of the mother plant.

a. Reproduction from Seed.

This is the more common form of reproduction, and on it depends the regeneration of high forest.

The greater the production of seed, and the higher its quality, the more assured is reproduction; both quantity and quality of the seed depend on the age of the trees, the locality, the available light, and on the species.

(1.) *Age.*—The first point of interest is the time when the various species commence to produce seed fit to germinate. Apart from single trees here and there, the average period may be placed as follows,* in the case of trees grown in regular woods:—

At the age of 25—30 *years:* Mountain Pine, Birch, White Alder, Aspen, Acacia.

* According to Hess.

At the age of 30—40 *years:* Scotch Pine, Black Pine, Weymouth Pine, Larch, Maple, Common Alder, Lime, Horse Chestnut.

At the age of 40—50 *years:* Hornbeam, Elm, Ash, Sycamore.

At the age of 50—60 *years:* Spruce, Sweet Chestnut.

At the age of 60—70 *years:* Beech.

At the age of 70—80 *years:* Silver Fir, Cembran Pine, Oak.

The most favourable age for the production of seed is, ordinarily, that when the principal height-growth is about to be completed, and when an extension of the crown takes place; in other words, when the individual tree lays on its maximum volume-growth. At that period the best seed is produced. Younger trees produce larger but fewer seeds; older trees produce more numerous but smaller seeds.

(2.) *Locality.*—Temperature is of first importance; where that is deficient, the production of seed is seriously endangered. Tree seeds contain a comparatively large proportion of ashes, and their production necessitates increased assimilation of substances from the soil; hence fresh fertile soils produce more and better seed than poor soils.

Some species no longer produce seed fit to germinate (or only in small quantities) when they have been cultivated beyond the limits of their natural home, as, for instance, Sweet Chestnut and Elm in England. Other species are very accommodating in this respect, such as Birch and Scotch Pine.

(3.) *Light.*—Increased assimilation requires an in-

creased amount of light to the crown; hence trees growing in the open produce more seed than those hemmed in. Suppressed trees do not produce seed.

(4.) *Species.*—The power of reproduction from seed differs considerably in the case of different species; it depends on the total quantity of good seed produced during a certain period, or on an average annually. The quantity of seed is governed by two things:—

(1.) The average yield of each seed-year; and
(2.) The frequency of seed-years.

As regards the average yield per seed-year, the species can be arranged into two sections as follows*:—

Heavy crops: Beech, Oak, Spruce, Scotch Pine, Birch, Hornbeam, Elm, Alder, Aspen, Willow.
Lighter crops: Ash, Maple, Sycamore, Silver Fir, Larch.

On the other hand, the species may, as regards frequency of seed-years, be arranged as follows:—

Beech seeds only after intervals of six, eight, ten, and even more years.
Oak, Spruce, Scotch Pine, Alder, and Ash, seed, on an average, every three to five years.
The remaining species seed after shorter intervals, and some do so every year.

Taking both factors into consideration, the species may be arranged into the following scale:—

* According to Gayer.

Best: Birch, Aspen, Willow.
Next: Scotch Pine, Spruce, Elm, Hornbeam.
Next: Maple, Sycamore, Silver Fir, Larch, Lime, Oak, Alder, Ash.
Last: Beech.

Another very important point is the size and nature of the seed. Species which have a small, light, and winged seed reproduce themselves more easily and extensively, than those with a heavy or wingless seed. Moreover, it so happens, that the species with light or winged seeds, such as Birch, Aspen, Willow, Scotch Pine, Spruce, are comparatively less sensitive in respect of the factors of the locality, than, for instance, Oak, Beech, Silver Fir, Maple, and Sycamore, with their heavy seeds. The consequence is, that the power of reproduction peculiar to the first-named species is much greater than that of the last-mentioned species. Instances where Oak and Beech are ousted by Scotch Pine and Spruce can be frequently seen, while the latter, in their turn, have to struggle against the inroads made on them by Birch, Aspen, and Willow.

b. Reproduction from Stool-shoots and Root-suckers.

This method of reproduction applies to coppice woods. It occurs in two ways:—

Either: On that part of the stem which remains, after a tree has been cut down, "dormant or adventitious buds" develop into shoots; they are called "Stool-shoots."

Or: Buds are formed on the roots, which develop into aërial shoots, such shoots being called "Root-suckers."

In both cases the nourishment and growth of the new individual depend on the continued root activity of the mother plant. If the new individual is capable of producing root-buds and of developing them into roots, it becomes independent of the mother plant; in such a case reproduction is established by a division of the mother plant.

Reproduction in the manner just described is strongest during youth, and the faculty is maintained for different periods of time according to species. The better the conditions of growth, the longer will the reproductive power be maintained. A thin and young bark reproduces more freely than thick and old bark. Favourable places are the neck of the root stalk and wounds.

An essential condition of a copious reproduction in the manner described is full enjoyment of light; stools standing under cover develop either no shoots or only feeble ones.

As regards species, the following classification may be made:—

The Reproduction is maintained beyond an age of 40 *years in the case of:* Oak, Sweet Chestnut, Hornbeam, Elm, Alder.

It ceases at an earlier age in: Beech, Birch, Maple, Sycamore, Ash.

The Conifers have no power of reproduction of this

class worth mentioning. Larch shows best amongst Conifers, and the three-leaved Pines next.

Some species produce only stool shoots, others root-suckers, and others again both :—

Principally stool-shoots: Oak, Hazel, Hornbeam, Beech, Elm, Sweet Chestnut, Lime, Black Poplar, Alder, Ash, Sycamore, Maple, Willow, Birch.

Principally root-suckers: Aspen, White Alder, False Acacia.

CHAPTER III.

CHARACTER AND COMPOSITION OF WOODS.

In Sylviculture trees are only in exceptional cases reared in free positions; as a general rule they are grown in considerable masses, which form more or less crowded woods. Such woods may be composed of one species only, or they may contain a mixture of two or more species; in the former case they are called "pure woods," and in the latter "mixed woods." Natural pure woods occur only under certain conditions, as, for instance, when the factors of the locality suit only one particular species, or when the vitality and energy of one species has gradually ousted all others. Species which appear naturally in pure woods, are called "gregarious." The bulk of the pure woods, which exist at present in Europe, are the result of artificial interference. By far the greater number of natural woods are mixed.

Section I.—Pure Woods.

Practically, woods are rarely quite pure, because in most cases specimens of other species, which it was not intended to rear, make their appearance uninvited. As long as such an admixture is slight, accidental, and not taken into account by the management, the character of the pure wood may be said to be preserved.

The principal advantage of pure over mixed woods is, that they are easier to manage, because the requirements of only one species have to be considered. On the other hand, they have considerable disadvantages as compared with mixed woods, which will be dealt with in Section II.

The fitness of a species to be raised in pure woods depends on its capacity to preserve, or even improve, the factors of the locality, in other words, whether the species preserves a complete leaf canopy to an advanced age, and secures the accumulation of a sufficient layer of humus. As indicated in Section IV. of Chapter I., Beech, Silver Fir, and Spruce act most beneficially in this respect, and next to these some of the Pines. These are called "*ruling*" species. Apart from them, several others are frequently grown in pure woods, such as Oak, Larch, and Willows, on account of their great utility.

Of the remaining, or so-called "*dependent*" species, few are found in pure woods, and then only under special circumstances; for instance, Hornbeam replacing Beech in frost localities, Cembran Pine and Mountain Pine at high elevations, Maritime Pine on dunes near the sea-shore, Birch in high latitudes.

What has been said above is, however, subject to exceptions in the following cases:—

(1.) If the factors of the locality are such, that an imperfect cover and want of humus do not materially injure them; as in deep fertile soils, which enjoy an ample and well-distributed rainfall, or which are kept moist by ground water or irrigation.

(2.) If the woods are treated under so short a rotation, that they are cut over before any excessive interruption of the leaf canopy has set in.

(3.) If the object is to utilize localities which are only fit for certain species; for instance, Alder and Willow on wet soils, Hornbeam in frost localities, etc.

(4.) If only one species finds a ready market, or is required for a special purpose.

Except in such cases, all dependent species should be raised in mixed woods.

Section II.—Mixed Woods.

A mixed wood may be so arranged that every tree of one species alternates with a tree of another species, in which case the mixture is called one *"by single trees."* Or a group of trees of one species may alternate with a group of trees of another species, called a *"mixture by groups"*; in the latter case the groups must not be of such extent, that each acquires the character of a pure wood.

Mixed woods may be:—

(*a.*) Permanent or temporary.

(*b.*) Even-aged or uneven-aged.

Temporary mixtures are ordinarily called for in the following cases:—

(1.) When the intention is to obtain an early return, by the removal of one of the species, which should in that case be of rapid growth.

(2.) When a tender species has to be protected

(nursed) during early youth against frost or drought, as Beech and Silver Fir, and to a less degree Oak. In this case a hardy and fast-growing species, such as Scotch Pine, Larch, Birch, is raised either simultaneously or beforehand, and removed when the tender species requires no further protection.

(3.) When both the above objects are combined.

Permanent mixtures are established, because they are considered to have advantages over pure woods.

1. *Advantages of Mixed Woods.*

(*a.*) Mixed woods admit of a more complete utilization of the factors of the locality, and consequently they produce a larger quantity of wood, if they are suitably arranged. Each spot can be stocked with the species which is best adapted to the factors of the locality; hence increased production.

(*b.*) Unless very extensive areas are available, only mixed woods enable the forester to meet the various demands of the market. In the case of pure woods, and if a regular annual yield of each of several species is expected, a complete series of age gradations is required for each species, which, in the case of a limited area, would lead to small annual cuttings. For instance, if the intention is to grow five species on an area of 500 acres under a rotation of 100 years, each cutting would extend, in the case of pure woods, over one acre, while in the case of a mixed wood, the annual cutting may be five acres in one block.

It should also be noted, that only a few species are fit to be grown in pure woods. At the same time many of the other species yield a very superior quality of timber, or valuable minor produce. All these would more or less disappear under the system of pure woods, or at any rate they would not thrive so well and would not develop equally fine boles, as if grown in mixed woods. Large-sized timber of many light-demanding species can only be produced by mixing them with shade-bearing, and consequently soil-preserving species.

(*c.*) Many species suffer less from external injurious influences, such as wind, fire, frost, snow, insects, fungi, if raised in mixture with other more hardy species.—A shallow-rooted species had best be grown mixed with a deep-rooted species.—Conifers are less exposed to damage by fire or snow, if mixed with broad-leaved species.—Insects are less dangerous in mixed woods, as they generally attack only one out of several species; moreover birds, the great insect destroyers, are more numerous where broad-leaved trees grow, than in pure coniferous woods.—Damage from fungi is also considerably less in the case of Conifers which are mixed with broad-leaved species.—A hardy species mixed with a tender species protects it against frost and drought.

(*d.*) Mistakes made in the selection of species can be more easily rectified in mixed than in pure woods. The suitability of a locality for a certain species is not always apparent at the outset; in the case of mixed woods, the species which is least suited can be removed at the time of thinning.

(*e.*) For the above reasons, mixed woods must, on the whole, yield better returns than pure woods.

(*f.*) Finally, mixed woods increase the artistic beauty of a country.

2. *Disadvantages of Mixed Woods.*

It is frequently described as a disadvantage of mixed woods, that their natural regeneration is more difficult than that of pure woods. No doubt, different species require different conditions, if natural regeneration is to be successful. More especially the cover of the mother or shelter trees must be more open where a light-demanding species is to be regenerated, than in the case of a shade-bearing tender species. The shelter, for instance, which suits the Beech, would probably kill young Oak seedlings. Again, certain species, such as Spruce, produce so much seed, spring up so easily, and would take possession of so much ground, that other species, like Beech, would have little chance of coming up in sufficient numbers. These objections are undeniable, but they are, after all, not of such importance as might appear at first sight. In the first place, the mother trees can be so selected, that one species is favoured against the others. Secondly, the surplus regeneration of any one species can be removed in the first thinnings. Thirdly, the species can be arranged in small groups. Fourthly and chiefly, the best procedure is, to regenerate naturally with special reference to one species, and to introduce the others (as far as necessary) artificially. In this manner the forester can produce the desired proportion of the several species with almost mathematical accuracy. On the whole, mixed woods offer such substantial advantages over pure woods, that the

slight disadvantages which can be advanced against them are considerably more than counterbalanced.

3. *Rules for the Formation of Mixed Woods.*

The advantages of mixed woods, which have been detailed above, will only be realized under certain conditions, the more important of which are the following:—

(*a.*) The locality must be, *a priori*, suitable for the favourable development of each of the species in mixture.

(*b.*) The mixture must be of such a nature that the factors of the locality do not suffer; on the contrary, they must, if possible, be improved. This will only be the case if the principal, or more numerous species, is soil-improving. As indicated above, exceptions occur when woods are treated under a short rotation, or when the quality of the locality is such, that it does not require to be assisted by the improving action of the trees growing on it.

(*c.*) The mixture must be so arranged that one species does not oust the others, and thus establish a pure wood. The excessive development of one species may be detrimental to the others, or even kill them outright. In this respect the toughest and least sociable species carries the day, these qualifications being dependent on shape, light-requirement and height-growth of the species.

Shape.—Each species must be given that growing space which is required for its proper development. In this

respect the several species differ considerably. Conifers, for instance, have a different shape from broad-leaved species. Again, some species are better able than others to stand an infringement on their proper growing space. Thus, the broad-crowned Oak is liable to suffer considerably in crowded woods, while Spruce stands an infringement of space comparatively easily.

Light-requirement.—The mixture must be so arranged that the light-demanding species are not likely to be shaded by other trees; in fact, they must have their heads free and exposed to the light. Some species like, and even require, some shelter during early youth, such as Silver Fir and Beech. Mixtures should be so arranged as to provide such shelter, whenever it is required. After the first few years, no species actually requires shade, and then species are either shade-bearing or light-demanding. In most cases the former will bear the shade of the latter, but not the reverse.

Height-growth.—All space-demanding and light-requiring species, when mixed with species of an opposite nature, must be of quicker height-growth than the latter. Hence the relative height-growth of the species must be fully considered in deciding on the nature of the mixture. In many cases it is necessary to produce woods of uneven age, in order to prevent the light-demanding species from being overgrown and suppressed by the other species.

Assuming then, that the locality suits generally all the species to be mixed, the following rules govern the selection and formation of mixtures:—

First Rule.—The principal (more numerous) species shall be soil-improving.

It has been stated above under what conditions exceptions from this rule are admissible.

Second Rule.—Shade-bearing species may be mixed with each other, provided their height-growth is of the same rapidity, or the slower growing can be effectually protected against the faster growing.

Third Rule.—Shade-bearing species may be mixed with light-demanding species, if the latter are either faster growing or are given a start.

To prevent the shade-bearing species being kept back in its growth it should be more numerous than the light-demanding species.

Fourth Rule.—Two or more light-demanding species should not be permanently mixed, because the soil deteriorates, and the faster growing suppresses the slower growing species.

Exceptions from this rule are admissible:—

(*a.*) On very fertile localities.
(*b.*) On very inferior localities, where nothing else will grow.
(*c.*) If the wood is treated under a short rotation.

Temporary mixtures of two or more light-demanding species occur frequently, especially where a slower growing species has to be protected against frost or drought; for instance, Oak with nurses of Larch, Scotch Pine or Birch.

Fifth Rule.—The circumstances of each case must decide whether the species shall be mixed by single trees or groups.

Two shade-bearing species of equal height-growth, for instance, may be mixed by single trees, but if the quality of the soil changes from place to place, it may be desirable to arrange the mixture according to groups, placing each species on the more suitable spots. Again, if a light-demanding species is to be raised with a faster growing species, the mixture should be by groups, and not by single trees.

All mixtures may be brought under one of the following three classes:—

Mixtures of Shade-bearing Species.
" " Shade-bearing and light-demanding Species.
" " Light-demanding Species.

4. *Mixtures of Shade-bearing Species.*

It is a general rule that the permanent preservation of a mixture becomes more difficult in the same degree as the species to be mixed differ in respect of light requirement, rate of height-growth, suitability of locality, and shape of tree. The ordinary European shade-bearing species approach each other in these respects; hence in their case the mixture is comparatively easy to maintain, and they may, generally, be raised in woods of even age or nearly so.

a. *Mixtures in High Forest.*

(1.) *Silver Fir and Spruce.*—These two species resemble each other as regards shape. They differ somewhat in their demands on the locality, but over extensive areas both find suitable conditions for a healthy

development. They are both shade-bearing, but Silver Fir more so than Spruce. The most important point is, that Spruce grows somewhat quicker during youth and is likely to injure the Silver Fir, but when the latter has once pushed its head to the light the two species hold their own against each other. In order to get the Silver Fir safely over the first 20 or 30 years it must be assisted against the Spruce by *either* giving it a start of 5—10 years, *or* arranging the mixture according to groups, *or* cutting away the Spruce where it threatens the Silver Fir.

The advantages of the mixture are principally the following:—

(*a.*) Spruce protects Silver Fir against frost and drought during early youth.

(*b.*) Silver Fir protects Spruce against storms in after life.

(*c.*) Spruce, when mixed with Silver Fir, is somewhat less exposed to damage by insects and snow.

(*d.*) The production of wood per acre and year is increased.

(2.) *Silver Fir and Beech.*—They differ in shape but make very similar demands on the locality. Both are highly shade-bearing. Beech grows somewhat quicker in youth but slower in after life (see Diagram on page 163). During the former period Silver Fir, and during the latter Beech, must be somewhat assisted, or the mixture must be arranged by groups.

Both species thrive better in mixture, which is altogether an excellent one.

(3.) *Spruce and Beech.*—They differ in shape, and

make somewhat different demands on the locality, especially in respect of the degree of moisture and depth, Spruce requiring more moisture, and Beech greater depth. Nevertheless, soil which is suited for Beech, will also do for Spruce, but not always the reverse; in the moister parts Spruce should predominate, and in the drier parts Beech. Both are shade-bearing, Spruce somewhat less so. The rate of height-growth is a more serious matter. During youth Beech grows frequently quicker, but afterwards Spruce; they must be protected accordingly, the one against the other. On the whole, Beech is more in danger of being suppressed than Spruce, because under ordinary circumstances the latter is more pushing and aggressive. Spruce is only threatened in localities which are specially suited to Beech.

Beech has a most beneficial effect upon Spruce in respect of danger from wind, snow, insects, and fire. At the same time, Beech produces finer boles in this mixture than if grown pure. Where Beech timber is little in demand, it should not occupy more than about $\frac{1}{4}$th of the area against $\frac{3}{4}$ths occupied by the Spruce.

(4.) *Beech and Hornbeam.*—This is a mixture of subordinate importance. The timber of Hornbeam is frequently more in demand, but Beech yields a larger volume. Hornbeam grows somewhat quicker at first, but on the whole it is left behind by Beech. In some localities, especially those exposed to frost, Hornbeam forms a suitable substitute for Beech in mixed woods.

b. Mixtures in Coppice Woods.

In Coppice woods it is always desirable to mix some Hornbeam with the Beech, because the latter by itself is rarely able to maintain a full crop, owing to its inferior reproductive power from the stool; Hornbeam is possessed of an almost indestructible reproductive power through stool shoots. Care is required to prevent the Hornbeam ousting the Beech.

In Coppice with Standards also, the underwood should consist, at any rate partly, of Hornbeam, and not altogether of Beech.

5. *Mixtures of Shade-bearing with Light-demanding Species.*

While the shade-bearing species much resemble each other in character, considerable differences exist between light-demanding and shade-bearing species in respect of shape, height-growth, light requirement and duration of life; hence the maintenance of such mixtures requires great care and skill.

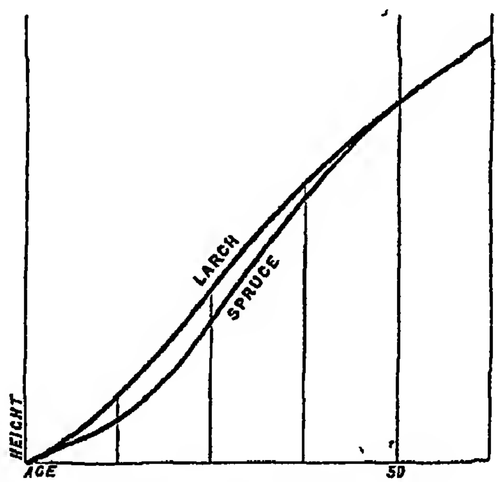
Most of the light-demanding species, such as Oak, Larch, Ash, Maple, Sycamore, are raised principally for timber and less for firewood; they require full enjoyment of light throughout life, but they cannot reach timber-size and maintain the factors of the locality without the assistance of the shade-bearing species; it is no longer sufficient to place each species into groups, and in order to meet the requirements of the case, *it is, generally, necessary to grow uneven-aged woods.*

The principal object in all such mixtures is the full development of the timber-yielding, light-demanding

species, while the shade-bearing species, though more numerous than the former, practically take the second place in importance. The light-demanding species which deserve special mention in this place are:—Larch, Scotch Pine, Oak, Maple, Sycamore, Ash, Elm, Birch, Lime, Aspen and Willow.

a. Mixtures in High Forest.

(1.) *Larch in mixture with Shade-bearing Species—Larch and Spruce.*—If the two species are of the same

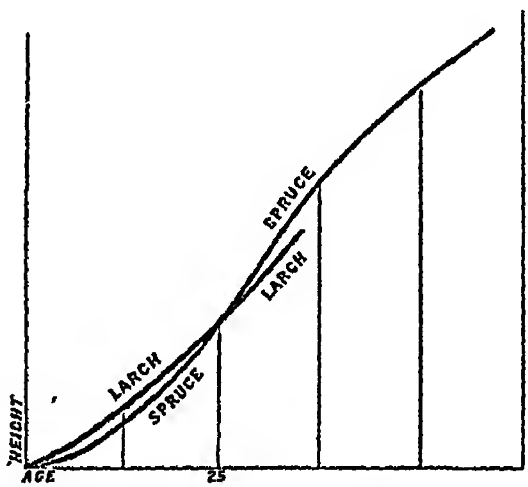


ON SOIL SPECIALLY SUITED TO LARCH.

age, the Larch goes ahead at once and leaves the Spruce behind. On soil which suits the Larch, the tree will not be caught up by the Spruce before the 40th or 50th year or even later, when they will grow up together. On localities which are less suited for Larch, the Spruce will catch it up much earlier, by the 15th to 25th year,

pass and suppress it, so that it gradually disappears. In such cases the Larch must be given a start, the result being an uneven-aged wood. The best method is, to plant Larch pure, and to bring in the Spruce when grass begins to replace the moss, that is to say, at the age of 20—30 years. When the Spruce has established itself, all Larches which are not likely to develop into fine trees should be removed.

It is well-known how much Larch suffers from cancer when grown outside its natural home. Until



ON SOIL LESS SUITED TO LARCH.

means have been found by which that disease can be prevented, the only way to reduce the damage to a minimum is, to isolate the Larch trees, by mixing them with another species, for which Spruce is fairly well adapted.

Larch, and Silver Fir.—This is a still better mixture than Larch and Spruce, as Silver Fir grows somewhat slower during youth than Spruce; otherwise the relative height-growth is much the same. As

Silver Fir requires better soil than Spruce, the Larch thrives admirably in all localities where Silver Fir grows, provided the mixture is arranged judiciously.

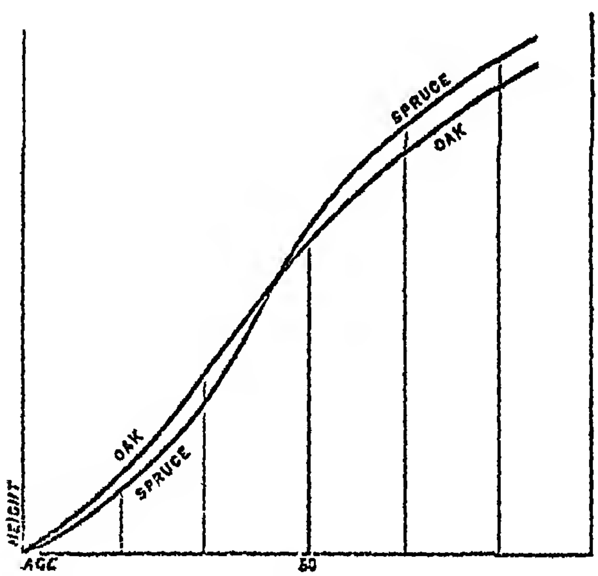
Larch and Beech.—This is an excellent mixture. Larch grows quickly enough to maintain itself in the even-aged form, but it is still better to start with pure Larch and to bring in the Beech, when the former is 20 to 30 years old. The most suitable localities are those with a fresh deep soil on northerly or easterly slopes.

(2.) *Scotch Pine in mixture with Shade-bearing Species.*—The Scotch Pine resembles the Larch very much in its bearing towards the shade-bearing species. The even-aged form does very well in the majority of cases. In the uneven-aged form, Spruce, Silver Fir or Beech need not be brought in until the Scotch Pine has reached the age of 30—40 years, as it begins to thin out somewhat later than the Larch. The Scotch Pine must not be too numerous, or its shade may injure the other species in the uneven-aged form as well, as during youth in the even-aged form.

Both Scotch Pine and Larch afford excellent protection against frost and drought to Silver Fir and Beech during their tender youth, and also to Spruce, though the latter requires such protection in a less degree than the former two species.

Scotch Pine and Hornbeam occur sometimes together, especially in frost localities, where the Hornbeam replaces the Beech. Hornbeam is liable to suffer considerably from the shade of the Scotch Pine, so that it is frequently reduced to an underwood, which should be periodically coppice.

(3.) *Oak in mixture with Shade-bearing Species—Oak and Spruce.*—Natural mixtures of Oak and Spruce are rare, owing to the different character of the two species. Oak is at home in low warm situations, Spruce in cool high places. Oak thrives best on loose, warm, deep soils with a good measure of water in the subsoil; Spruce requires moisture near the surface, and it is satisfied with a moderately deep soil. Oak requires



much light, heat and space; the demands of Spruce are more moderate in these respects. Oak is inclined to develop large branches; Spruce grows more in height. Nevertheless, artificial mixtures of the two species are advocated by some foresters. Oak grows faster than Spruce during youth; later on Spruce passes the Oak, and the latter has no chance if mixed by single trees in even-aged woods. It is necessary to place the

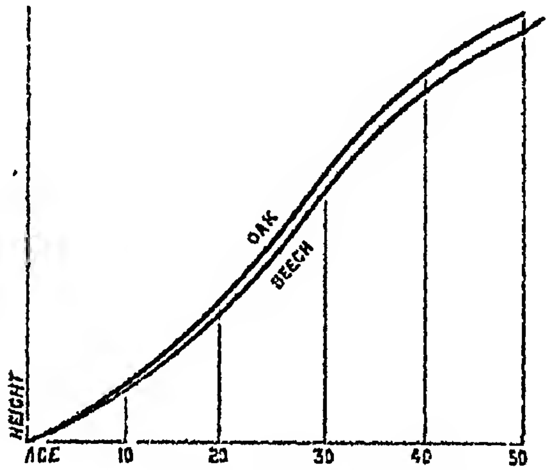
Oak in groups, and even then it does not always develop satisfactorily. The best arrangement is to plant Oak pure and to bring in the Spruce when the Oak commences to thin out. It has, however, been noticed that the Oak becomes stag-headed when under-planted with Spruce, a phenomenon which is by some foresters believed to be due to the great consumption of water by the Spruce.

Oak and Silver Fir.—This is a better mixture than that of Oak and Spruce, as the two species resemble each other more in their demands on the locality. Oak requires a start, or it will be passed at about middle age and suppressed by Silver Fir. The best plan is to plant Oak pure, and to bring in Silver Fir when the former begins to thin out.

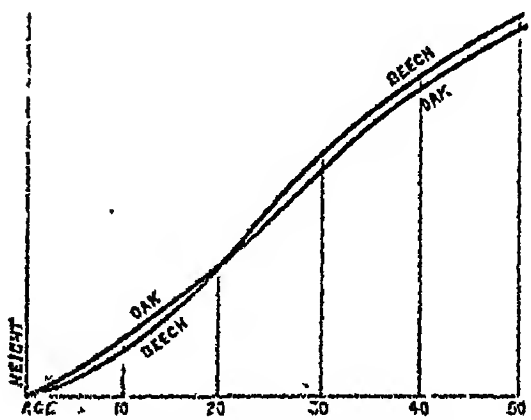
Oak and Beech.—This is a most suitable mixture, as the two species stand sufficiently near each other in respect of locality and shape; moreover, they are found naturally together. The Beech has been called the Oak's nurse. The Oak finds in the mixture all the advantages of a permanent complete shading of the ground, accompanied by a heavy fall of leaves, a thick layer of humus, and freshness of the soil; it thus attains great height and a clear bole of considerable length.

The Oak requires to have its head free throughout life. It grows quicker than Beech, wherever the climate and soil suit it in respect of moisture and depth. In such localities the mixture should be arranged by single trees. In less favourable localities the Oak sinks below the Beech, and then the former, in single trees, is lost; hence the mixture must be

arranged by groups, or better still, the Oak must be given a start, the Beech being brought in when the Oak



On Localities suitable to Oak.



On Localities less suitable to Oak.

commences to thin out, that is to say, between the 30th and 60th year, according to circumstances.

Oak and Hornbeam.—This mixture may be desirable

in localities which do not suit the Beech, as for instance in frost localities, or moist deep sandy soils of the low lands. The Oak grows quickly enough to hold its own against Hornbeam. In this mixture the Hornbeam is frequently treated as coppice.

(4.) *Maple and Sycamore in mixture with Shade-bearing Species.*—Mixtures of this class require a fresh, deep and fertile soil. During early youth both Maple and Sycamore grow quicker than Spruce, Silver Fir, and Beech, but later on they are passed by the shade-bearing species. Hence it is necessary to place the Maple and Sycamore in groups, or to give them a start in age.

(5.) *Ash in mixture with Shade-bearing Species.*—The best mixture is Ash and Beech; not so good is that of Ash and Silver Fir, and still less that of Ash and Spruce.

Ash, like the Maples, grows first more quickly than Beech, but is generally passed by the latter later on, hence it should be placed in groups in the moister parts of the locality. Where Ash occurs pure, it should be underplanted with Beech before its height-growth has been completed.

(6.) *Elm in mixture with Shade-bearing Species.*—Elm does best in mixture with Beech, or perhaps Hornbeam. The mixture of Elm with Spruce and Silver Fir is less desirable. Elm requires a locality with sufficient warmth, or else it will not develop into a large-sized tree; it also requires a deep fertile soil. Elm grows at first quicker than Beech, but afterwards it is liable to be passed, hence it must be placed in groups, or

given a start. The groups should subsequently be underplanted with Beech.

(7.) *Birch in mixture with Shade-bearing Species.*—Such mixtures occur naturally. The light seed of the Birch settles on all blanks, large or small, and too often interferes with the shade-bearing species.

Birch and Beech.—The Birch should only form a moderate admixture by single trees; if it is more numerous, a part should be cut back. Birch becomes ripe for the axe long before the Beech.

Birch and Silver Fir.—After some time the Silver Fir outgrows the Birch, which is then likely to be suppressed.

Birch and Spruce.—The Birch injures the Spruce by a whip-like action of its branches, but Spruce soon passes and suppresses Birch.

(8.) *Lime, Aspen, and Willow in mixture with Shade-bearing Species.*—Like Birch, these species appear naturally amongst shade-bearers, more especially in Beech woods, where they often do damage owing to their rapid growth in early youth. If it is desired to produce large specimens of these species, they must be reduced to moderate numbers. In after life, Beech passes and suppresses them, if allowed to do so.

b. Mixture in Coppice with Standards.

The greater part of the mixture consists of broad-leaved species, but conifers (Larch, Scotch Pine, &c.) are not excluded, so that an opportunity is given for the production of any or all species.

It must be a leading principle to let the light-

demanding species prevail in the standards, or *overwood*, and the shade-bearing species in the coppice, or *underwood*. At the same time, some individuals of the latter species may be represented in the overwood, for the purpose of producing seed to meet the requirement of natural regeneration when required.

The overwood should consist of healthy trees which, if possible, have been raised from seed. Only in exceptional cases should vigorous coppice shoots be allowed to grow into standards.

In some cases all ages are mixed by single trees, in others the several age gradations are arranged in small groups. As the coppice shoots at once grow rapidly, seedlings have no chance of making their way up, unless they are strong, and are protected against the coppice shoots.

As each standard must be cut when it has reached the highest degree of usefulness, it follows that Larch, Scotch Pine, and Birch will fall under the axe before the Oak, Elm, Maple, or Sycamore have reached a useful size; hence the former do not appear in the oldest age-classes.

c. Mixture in Coppice.

The principal species are Beech, Hornbeam, Elm, Ash, Maple, Sycamore, Lime, Oak, Sweet Chestnut, Birch, Hazel, Willow, Aspen, etc.

Beech is slower growing than the light-demanding species, and it requires some protection against them except on very fresh and fertile soils. Ash, Maple, Sycamore, and Oak are liable to suffer from too large a proportion of Birch, Hazel, and Willow.

6. *Mixtures of Light-demanding Species.*

As indicated above, such mixtures are justified only in exceptional cases. Generally, they are objectionable, as long as the admixture of a shade-bearing species is practicable.

All mixtures of light-demanding species thin out sooner or later according to the degree of light-requirement and the tendency towards branch formation of the species, as well as according to the quality of the locality. When once that period has arrived, the factors of the locality must suffer. Exceptions are woods growing under favourable conditions, temporary mixtures and shelter-woods.

Generally, only the even-aged form is admissible, and even then such mixtures require constant attention, so as to prevent one species being suppressed by the other.

a. Mixture in High Forest.

(1.) *Oak, with Ash, Elm, or Sweet Chestnut.*—These mixtures require a fertile, deep, moist soil, and a favourable climate. Oak is slower growing during early youth, and in many cases also later on; hence it is liable to be suppressed. At any rate it rarely finds sufficient space for favourable development, being closely pressed by the other light-demanding species. It does better if placed in groups.

(2.) *Oak with Alder and Birch.*—This mixture occurs on wet soil, where the Oak occupies the drier parts; the latter rarely does well in such localities.

(3.) *Oak with Scotch Pine or Larch.*—Such mixtures

are made because Oak helps to protect the Scotch Pine against damage by insects, snow, etc., and Larch against canker, while Scotch Pine and Larch protect the Oak during youth against frost and drought. If for the latter purpose, the mixture is frequently of a temporary nature, or only a few Scotch Pines or Larches are allowed to remain when the Oak does no longer require shelter.

(4.) *Scotch Pine with Birch.*—This mixture occurs naturally, and yet it cannot be recommended, because such woods are always very thin, followed by a deterioration of the soil. They are generally the result of unfavourable conditions in localities where neither species is able to compete with Scotch Pine and Birch.

Up to 15 or 20 years Birch grows quicker; the Scotch Pine, if it survives that period, comes up and passes it soon; the Birch then requires help, if it is to be preserved. Birch falls under the axe at a comparatively early age, and an open wood of Scotch Pine remains. Only on good fresh soil does Birch last until the Scotch Pine has reached a marketable size.

At the same time Birch may be a desirable admixture, where the object is to protect the Scotch Pine against insects, snow, fire, etc., and where a more suitable mixture is impracticable.

(5.) *Scotch Pine with Larch.*—This mixture leads to unsatisfactory results whenever the locality is not thoroughly suited to Larch. During youth, up to 15 or 20 years, Larch grows quicker and may injure the Scotch Pine. If the Scotch Pine makes its way up and begins to press round or pass the Larch, the latter must disappear.

Nevertheless, this mixture occurs over extensive areas in the United Kingdom, not because it is the best that can be devised, but because Scotch Pine thrives well and yields higher returns than most of the shade-bearing species which could be substituted for it.

Other mixtures, in which the Scotch Pine is the principal species, are:—

Scotch Pine with Aspen or Alder; not to be recommended.
" " " Weymouth Pine; a fairly good mixture.
" " " Black Pine; the latter disappears, as it is slower growing.
" " " Sweet Chestnut; the latter often becomes a soil-protection wood.

(6.) *Alder with Birch and Aspen.*—This mixture occurs in wet localities, where nothing else will grow.

b. Coppice, and Coppice with Standards.

Woods of Coppice with Standards consisting of light-demanding species only, are comparatively rare, as the standards must either be very few in number, or the underwood suffers. Under any circumstances such mixtures require a very fertile soil. Mixtures of this kind are, for instance—

Ash and Alder, or
Oak, Ash, Elm, Hazel and others.

Where Ash and Alder appear in mixture, the former should, generally, be the overwood, and the latter the

underwood; it occurs in wet localities. In fertile low lands Oak appears as overwood and underwood, mixed with various other species, as Ash, Elm, etc. Short stems of the standards and injured underwood are often the characteristics of such mixtures.

Coppice woods coming under this heading are mixtures of Oak, Birch, Lime, Aspen, Sallow, Hazel, and more especially Oak with Sweet Chestnut. In such mixtures Scotch Pine and Larch often find a temporary place as small standards.

Another mixture is that of Sweet Chestnut and Acacia, generally by groups, or else Acacia is likely to suffer.

CHAPTER IV.

THE SYLVICULTURAL SYSTEMS; OR, METHODS OF TREATMENT.

UNDER a sylvicultural system is understood the systematically arranged method according to which the creation, the regeneration, the tending, and the utilization of the woods, which compose a forest, are effected.

The character of each system depends in the first place on the method of creation or regeneration, and consequently all systems must come under one of the following three heads:—

(1.) High or seedling forest.
(2.) Coppice forest.
(3.) A combination of seedling and coppice forest.

Owing to the varying character in the factors of the locality, the composition of woods, and the many different purposes for which they are grown, the above three main systems have been split up into a number of variations. In the case of high forest the principal distinction is, whether the new wood is created on a clear cutting, or under the shelter of an existing wood. In the latter case, the regeneration may be effected at the same time in a uniform manner over a considerable area (compartment), or over certain groups, or by the removal of single trees here and there.

Coppice woods may consist of stool shoots or of pollards. Again, a number of auxiliary systems have been evolved out of the principal systems by means of certain modifications or additions.

It is not intended to describe here all existing modifications, but the more important systems may be classified as follows:—

I. Principal systems:—

A. High or seedling forest—

1. Clear cutting and subsequent regeneration 1
2. Regeneration under a shelter-wood:
   a. By compartments 2
   b. " groups 3
   c. " single trees 4

B. Coppice forest 5

C. Combination of seedling and coppice forest . 6

II. Auxiliary systems—
1. High forest with standards 7
2. Two-storied high forest 8
3. High forest with soil-protection wood . 9
4. Forestry combined with the growth of field crops 10
5. Forestry combined with the breeding of cattle 11
6. Forestry combined with the breeding of deer and game 12

Section I.—Description of Systems.

In considering the various systems the following points deserve special attention:—

(1.) Origin and character of wood.
(2.) External dangers peculiar to the system.
(3.) Quantity and quality of produce.
(4.) Effect of the system upon the factors of the locality.

The remarks on each of the twelve systems will be arranged under these four heads.

1. *System of Clear Cutting in High Forest.*

a. Origin and Character.

The wood is originated on an area which is clear of trees, by direct sowing or planting, or occasionally by seed coming from adjoining woods. The young trees are all of the same age and height (or nearly so); as soon as the branches commence to interlace, the trees form an uninterrupted leaf canopy overhead, which, with advancing years, becomes more and more elevated above the ground, leaving a space below, in which the branchless trunks or boles of the trees tend upwards.

In a wood of this class the sunlight reaches only the upper parts of the crown, the result being that height-growth and the formation of clear boles are specially favoured. The density of the cover, and with it the diameter-growth, depend on the character of the species, the quality of the locality, and the degree of thinning.

At the end of the rotation the wood is cleared off the area, and the process of creation recommenced.

b. External Dangers.

The principal dangers are those of frost, drought, insects and storms. In early youth a wood created on a cleared area is exposed to all meteoric influences. In winter frost threatens the young plants if they are at all sensitive to it, and in summer the uninterrupted exposure to the sun causes the drying up of the soil and plants. Moreover, air currents strike over the area without interference. There can be no doubt that many diseases, which show themselves perhaps only later on, can be traced as having originated during this period of early exposure. At that time the greater dryness of the soil attracts insects, which concentrate their breeding places in it, while the absence of trees causes insect-destroying birds to be comparatively scarce.

Whether woods produced under this system are more subject to damage by storms than woods produced under shelter-woods is doubtful, varying views being held on the subject. On the one hand, trees of even age standing in crowded woods protect each other, but on the other hand individually they do not stand as firm as trees grown up in a more free position or in woods of uneven age. What has been said about strong winds probably holds also good as regards damage by snow and ice.

c. Production of Wood.

As regards production, the system compares favourably with other high forest systems, especially if the

woods are created by planting. The quality of the timber is also of a very high class if the thinnings have been carried out in a judicious manner. More especially long clean non-tapering boles are produced under this system, to which a good diameter can be added by thinning strongly towards the end of the principal height-growth.

d. Effect upon the Factors of the Locality.

This effect differs much during the several periods of the life of the wood. During early youth, before a complete leaf-canopy has been established, the soil is exposed to the effects of sun and air currents, both of which act highly injuriously on the soil. Subsequently, when a good cover has been established, the very opposite effect is produced in a high degree. Later on in life again, when the crowns, with advancing age, have been elevated far above the ground, the sun is still kept out, but there is no impediment to air currents striking through the wood, so that moisture and Carbon Dioxide are carried away, and the activity of the locality is frequently considerably reduced by the time regeneration should be commenced.

It follows that the system has decided disadvantages where the supply of moisture is limited. At any rate, the production is subject to considerable fluctuations. In the case of shade-bearing species with dense crowns the system yields evidently much better results than in the case of light-demanding species with thin crowns. The length of the rotation also affects the results.

2. *The Shelter-wood Compartment System.*

a. Origin and Character.

The wood is created, or regenerated, under the shelter of the whole or part of the old crop, which forms the shelter-wood, and which is retained for some years until the young generation has established itself and is safe against injurious external influences peculiar to early youth. The regeneration is effected, according to circumstances, by the seed falling from the shelter-trees, which in that case become mother-trees, or by sowing and planting. In the former case the regeneration is said to be natural, in the latter artificial. In the case of natural regeneration, one seed year is rarely sufficient; generally two or three such seed years are required, and often artificial cultivation has to assist, in order to produce a full new crop; hence the latter shows in the majority of cases differences of age ranging up to perhaps 15 years. Nevertheless, such differences will be no longer discernible when the wood approaches the end of the period of principal height-growth, and, for all practical purposes, such woods are considered even-aged.

b. External Dangers.

Owing to the presence of the shelter-wood, the danger from frost and drought during youth is very considerably reduced, if not altogether obviated; during the rest of life no difference exists in this respect between this system and the system of clear cutting. It is believed that such woods are less attacked by insects than woods on clear cuttings. Little or no difference exists as regards

storms, except that the shelter-, or mother-trees, are liable to be thrown.

c. Production of Wood.

The quantity of total production is probably the same as in clear cutting. As regards quality it should be noticed that the mother-trees are in a position to attain a specially large size (diameter), owing to their comparatively free position during the last period of life.

d. Effect upon the Factors of the Locality.

The unfavourable effect of sun and air currents during the early youth of the wood disappears under this system, as the shelter-wood protects the soil until the new crop can relieve it of this duty. In after-life no difference exists between this system and that of clear cutting.

Some authors introduce an additional system as the "Shelter-wood Strip System." Under this system each compartment is divided into a number of narrow strips, which are successively taken in hand for regeneration. The system is, however, otherwise precisely the same as the Shelter-wood Compartment System, the compartments merely receiving the shape of comparatively narrow strips.

3. *The Shelter-wood Group System.*

This is a modification of the Shelter-wood Compartment System.

a. Origin and Character.

The wood is created, or regenerated, under the shelter of the old crop, but instead of taking a whole compartment in hand at one time, with a view to its simultaneous regeneration, only certain groups of trees scattered here and there over it are dealt with in the first place; when these have been regenerated, others are treated in the same way, and so on, until the whole compartment has been regenerated. The period of regeneration extends over not less than thirty, and often forty or fifty years, during which the old wood is gradually led over into the new wood. At the end of the regeneration period, the new wood consists of a series of groups, of greater or smaller extent, ranging in age from one to thirty, forty, or fifty years, according to circumstances, and it presents a picture of unevenness which is preserved throughout life. The wood grows on until the next regeneration comes round, when operations are commenced in the oldest groups and gradually, in the course of thirty, forty, or fifty years, extended to the youngest.

During regeneration all seed years are taken advantage of, and artificial help, where necessary or desirable, is not excluded.

b. External Dangers.

Owing to the uneven age of the several groups, the young growth receives both top- and side-shelter; hence it is more fully protected against frost and drought than under the Shelter-wood Compartment System. It is also claimed for the system, that the trees withstand

storms and damage by snow or ice better. In this respect further data are required before a final conclusion can be arrived at.

c. Production of Wood.

Whether the total production is greater or smaller than under either of the previously mentioned two systems, can only be proved by actual statistics in the course of time; the system affords the means of producing valuable large timber, as towards the end of the rotation, the finest trees can be placed comparatively free for a term of thirty to fifty years.

d. Effect upon the Factors of the Locality.

This is doubtless more favourable than under the Shelter-wood Compartment System, as the soil is more carefully sheltered, accompanied by a more complete preservation of an even state of moisture.

4. *The Shelter-wood Selection System.*

a. Origin and Character.

The forest is created, under the shelter of the old crop, by the removal of single trees or small groups selected here and there over the whole area, and this process goes on throughout the whole length of the rotation, so that practically no part of the forest is ever at rest. All age classes, from one year old to the oldest, are constantly represented, by single trees or small groups, over the whole area, and the work of selecting trees for cut-

ting extends at all times over the whole extent of the forest.

b. External Dangers.

Views differ somewhat regarding the extent to which selection forests are exposed to external dangers, as compared with the two previously mentioned shelter-wood systems. In the absence of exact comparative observations, it may be stated, that in respect of drought the selection system acts very favourably, because only very small plots are, at one time, exposed to sun and air currents. The same may be said, in the majority of cases, as regards frost. Nothing definite can be said in respect of damage by insects. As regards damage by wind, snow, etc., views differ.

c. Production of Wood.

Here again actual comparative observations are not available. It has by no means been proved that less wood per acre and per annum is produced under this than under either of the two previous systems. Young growth, no doubt, develops slowly, as it is much interfered with by the adjoining older trees, but this may be compensated for by a more active development when the trees have secured the full enjoyment of light, especially during the more advanced period of life. There can, however, be no doubt, that less clean and shorter boles are produced under this system than under the compartment system, though the former is specially suited for the production of large-sized timber, as each tree can be left in the forest until it has reached the desired dimensions.

d. Effect upon the Factors of the Locality.

The system secures an almost absolutely equal degree of protection of the soil throughout the rotation, more especially as regards the preservation of an even degree of moisture, which must act beneficially upon production. Protection is given not only from above, but the uniform mixture of old and young trees also secures lateral shelter.

On sloping ground rain water is more effectively retained under this than under any other system; avalanches also, the carrying away of fine earth, landslips, etc., are prevented; hence protection forests situated in mountains are usually worked under this system.

5. *The Coppice System.*

a. Origin and Character.

Most broad-leaved species have the faculty of reproducing themselves by shoots, which spring either from the roots, stool, or stem. After severing the whole, or part, of the stem above ground, the roots and stool develop shoots, which grow up into poles, and, under favourable conditions, into trees, thus producing a new generation. This process of regeneration can, as a rule, be repeated as long as the stool and roots continue to live.

When the trees are cut over close to the ground, *simple or ordinary coppice* is produced, the shoots starting from a point which is close to, or in, the ground. Generally, several shoots spring from the same stool, and these stand in clumps, and can easily be distin-

guished from seedling trees. On well-stocked areas a complete cover is established earlier under this system than in seedling forests, as the shoots develop very rapidly. When the cover has been established, the wood presents the appearance of an ordinary sapling wood in high forest.

If the trees are cut over at some height, say several feet, from the ground, the shoots appear at the upper end of the stem, which may be said to form a new crown. In that case the system becomes the *topping system* of coppice. If the main stems remain intact, or nearly so, and only the side branches are cut over, the method is called the *pollarding system.* No distinct line can, however, be drawn between these two systems, and in many cases topping and pollarding must be considered as synonymous terms. In either case the trees may be cut over repeatedly, just as in ordinary coppice.

b. External Dangers.

Coppice suffers more from late and early frosts than seedling forest, because the shoots grow up quickly, reach a considerable size during the first year, are full of sap, and consequently require a longer growing period in order to ripen before the autumn frosts set in. On the other hand, damage by frost is more easily repaired in the case of coppice, as new shoots will replace those injured during the first year. In respect of other sources of damage, coppice is less affected than high forest.

c. Production of Wood.

Coppice yields chiefly fire-wood, and small timber,

such as hop poles, vine props, rafters, withies for basket work, &c. Oak coppice woods are cultivated for the sake of the bark, which is used for tanning. The production of cubic feet per acre and per annum is generally smaller than in the case of high forest.

d. Effect upon the Factors of the Locality.

Owing to the rapid growth of the shoots and the quick establishment of a complete cover, coppice woods protect the soil well after the first few years, but the latter is laid bare at much shorter intervals than in the case of high forest. The higher the rotation, the more nearly does coppice wood approach the character of high forest; as a rule, however, the rotation is short and the wood does not reach that age, at which air currents obtain free access underneath the elevated crowns.

6. *Coppice with Standards (Stored Coppice).*

a. Origin and Character.

The system of coppice with standards is a combination of the following two systems:—

(1.) Simple coppice of even age, and
(2.) Standards of uneven age treated under the high-forest selection system.

The coppice forms the under-wood, and the standards the over-wood, the two being treated under different rotations. Generally, cuttings are made in both under- and over-wood at the same time, that is to say, when

the underwood has arrived at the end of its rotation it is cut over, and at the same time those standards are removed which have reached the end of the rotation fixed for the over-wood, or which it is desirable to remove for other reasons. New standards are then introduced, which, as a rule, should be seedlings and not coppice shoots. It follows that the several gradations of the over-wood show a difference in age equal to one rotation of the under-wood, and the age of the oldest standards at the time of cutting is a multiple of the number of years contained in the rotation fixed for the under-wood.

Example.

Rotation of under-wood . . . = 20 years.
Rotation of over-wood . . . . =100 „
Number of age gradations in over-wood $= \frac{100}{20} = 5$.

At all times the youngest age gradation forms part of the underwood, until the latter is cut over.

Every standard removed at the end of the rotation must be replaced by a younger tree. If all seedlings reached the end of the rotation, only one need be planted for every full-sized standard which has been removed, but as numerous seedlings have, owing to various causes, to be taken out before the end of the rotation, it is necessary to plant a number of seedlings for every mature standard removed, so that, as a matter of fact, the numbers of the standards always form a falling series. The actual proportion of trees in the several age gradations depends on circumstances. In the

above-mentioned example the proportion would be somewhat as follows :—

Number of age gradation .	I.	II.	III.	IV.	V.
Proportion of standards . .	20	12	3	2	1.

In other words, for every desired standard of 100 years old it is necessary to have 20 standards 20 years old, which will be reduced to 12 at 40 years, to 3 at 60 years, to 2 at 80 years, and to 1 at 100 years old. Though 38 standards are present on a certain area, only five reach maturity, the others being cut from time to time, thrown by wind or otherwise injured.

The actual number of standards per unit of area is governed by considerations for the underwood. If the standards are very numerous and give too much shade, the underwood will no longer grow. In practice a great variety of modifications have been introduced, according to whether the overwood or underwood is more favoured.

The *normal form* is that in which over- and underwood receive equal attention. Here the effect of the shade thrown by the overwood must always be carefully considered; above all, the shade should be evenly distributed over the area. It is always desirable that the bulk of the overwood should consist of species with thin crowns, in other words of light-demanding species.

Where *the overwood is favoured* the system approaches that of high forest. Here the object is to produce as much timber as possible, and the shade of the standards would be so heavy, if evenly distributed, that the underwood could no longer thrive; hence it is desirable to

place the over- and underwood into alternate groups. This will enable the underwood to thrive on the areas allotted to it, while the standards will produce straighter and cleaner boles than under the normal form.

If *the underwood is favoured* the system approaches that of Simple Coppice. The standards are here so far apart that they will not, as a rule, produce good timber unless they are brought together into groups here and there.

b. *External Dangers.*

These are very small compared with those peculiar to most other systems. To begin with, the overwood is, at any rate in the normal form, capable of protecting the underwood against frost and drought. Under any circumstances such damage does not occur regularly and does not endanger the existence of the wood.

Storms do remarkably little damage in such woods. The younger classes of standards are protected by the older classes, and by the time they replace the latter they have developed strong root systems, so that they can hold their own.

Insects do not more damage than in the Shelter-wood Selection System, and less than in all other systems, which is due to the variety of stocking, absence of cleared spaces or loosened soil, and to the greater number of insect-eating birds which are found in such woods.

c. *Production of Wood.*

It is possible that slightly less wood is produced than under the high forest systems, but at any rate the difference is not likely to be great. On the other hand the

system is specially adapted to the production of timber of all kinds and sizes. It affords opportunity for the individual development of the trees without endangering the factors of the locality. In one point, however, it is inferior to high forest, inasmuch as the shape of the trees is not so good; they are shorter and less clear of branches in the lower part of the stem.

d. Effect upon the Factors of the Locality.

If treated properly, coppice with standards acts highly beneficially upon the factors of the locality; the laying bare of the soil at the end of every rotation of the underwood is only very partial and of short duration.

7. *High Forest with Standards.*

a. Origin and Character.

During the regeneration of a high forest, single trees or groups of trees are left standing with the intention that they shall continue to increase in size for a further series of years. After the completion of the regeneration, such woods consist of a new crop and a number of standards scattered over it, either in single trees or in groups. The period during which the standards are retained differs from a few years to a whole or even two or more rotations.

b. External Dangers

Are the same as those of the original system, with this addition, that the standards are liable to be thrown by wind; hence only wind-firm species should be

selected for standards, and the system should not be adopted at all in localities which are specially exposed to storms.

c. *Production of Wood.*

Under this system timber is produced of such dimensions as cannot be grown under any ordinary high forest system, except under exceptionally high rotations.

d. *Effect upon the Factors of the Locality.*

Directly, the effect is the same as that of the principal system. Indirectly the system acts beneficially, as it obviates the adoption of very high rotations where specially large timber is required.

8. *Two-storied High Forest.*

a. *Origin and Character.*

In the life of most woods, especially if they consist of light-demanding species, a time arrives when the cover becomes interrupted, so that they can no longer preserve the factors of the locality. In the case of species where this time arrives at a comparatively early age a second crop can be introduced, generally by sowing or planting, which is allowed to grow up into high forest with and between the older crop, so that practically two distinct even-aged woods exist on the same area, both high forest, the difference in age ranging from 20—60 years, according to species and circumstances; hence the name of two-storied high forest. The two crops are

cut over at the same time, when the whole process is recommenced.

It is usual to thin the older crop heavily, either before or after the introduction of the second crop, by removing all diseased and badly-shaped trees, leaving those which promise to develop into fine sound timber trees.

The older crop should, in all cases, consist of light-demanding and the younger crop of shade-bearing species, or else the latter is not likely to thrive.

b. External Dangers.

The older crop may be subject to damage by storms, but generally only for a short period. Damage by frost in the case of the younger wood is excluded.

c. Production of Wood.

The system is well adapted for the production of large timber. During the first part of life the trees composing the upper storey grow up close together, developing height-growth and clean boles; in after life they are placed comparatively free and can rapidly increase in diameter.

The system yields also an early and substantial return in the way of a heavy thinning of the older wood.

d. Effect on the Factors of the Locality.

The system preserves the factors of the locality better than ordinary high forest, and deserves to be extensively followed in all cases where it is desired to produce large timber of light-demanding species.

9. *High Forest with Soil-protection Wood.*

When the leaf canopy in a high forest commences to become interrupted, an underwood is introduced for the protection of the soil. Such an underwood must be dense and not too old, hence it must either be replanted from time to time, or, still better, coppiced periodically; it must consist of species which can stand the shade of the overwood, the latter consisting of thin-crowned trees.

The effect on the factors of the locality is highly beneficial.

10. *Forestry combined with the Growing of Field Crops.*

The system of combining forestry with the cultivation of field crops is very old. Originally it consisted in cutting down a piece of forest, burning the wood, and using the land for one or more years for the production of field crops, and then allowing the forest to re-establish itself. When the value of forest produce increased some order was brought into the system in European countries; the timber, instead of being burnt, was utilized, only the twigs and other inferior pieces being burnt. The following are the two principal forms as now practised in Europe:—

a. Coppice combined with the Cultivation of Field Crops.

After each cutting over of the coppice wood, the twigs and other valueless pieces of wood, together with turf, are burned. This process is effected *either* by distributing the brushwood evenly over the area and letting the fire run over it, *or* by mixing it with turf,

piling it up in heaps and burning after the material has become sufficiently dry. In either case the ashes are scattered, the soil is worked, and then used for one or two seasons for the production of field crops, which grow between the new coppice shoots.

It is said that with proper care the yield of forests so treated is not smaller than that of ordinary coppice woods. The returns from the field crops do rarely more than cover the outlay on account of labour, seed corn, etc.; hence the system is now restricted to hilly parts, where a sufficient area of permanent fields is not available, and where additional occupation for the existing population is wanted, the forest lands not being of sufficiently good quality to make their conversion into permanent fields desirable.

The species of tree which is most commonly cultivated in this manner is the Oak, and next to it the Hornbeam, while Scotch Pine is frequently brought in after the cultivation of cereals has ceased to help in covering the ground.

The cereals usually grown are:—

Buckwheat—*Polygonum Fagopyrum* and *tartaricum*, L., and

Rye—*Secale cereale hibernum.*

The buckwheat is sown immediately after the clearing and burning, say in June, and harvested 6 or 7 weeks afterwards. The rye is sown in autumn and reaped in the following summer, when the cultivation of field crops ceases. In some cases the buckwheat and rye are sown together, the former being harvested in late summer of the first year, and the latter in the summer of the second year.

b. High Forest combined with the Cultivation of Field Crops.

After each cutting over of a high forest, the soil is used for one or more years for the growth of field crops. The young forest crop is established, either at once, or after the growth of cereals has ceased, by sowing or planting in lines, or by sowing broadcast with the last crop of cereals. In some cases the soil is burned over after the clearing of the forest crop, as described in the case of coppice.

In addition to buckwheat and rye, frequently oats, potatoes, etc., are grown.

c. Effect of the System on the Factors of the Locality.

The two variations of the system are subject to the ordinary disadvantages of the clear cutting system, and in addition the cultivation of field crops may exhaust the soil. Hence, they are only permissible where they are an absolute necessity, or on soil which can bear the strain of clear cutting and of the growing of field crops without becoming exhausted.

The system is still extensively practised in India under a variety of names, as jhooming, dhya, kumri, taungya cultivation, etc. There the whole of the old crop of wood is generally burned, so as to obtain as large a quantity of ashes as possible. Of late years the practice has been taken advantage of in Burma to produce young teak woods. The clearings are made in comparatively useless forest, the cultivator undertaking to sow or plant teak between his field crops, for which he is paid at an agreed rate at the end of the first, second, or third year.

11. *Forestry combined with the Rearing of Cattle.*

Pasture lands are widely planted with forest trees, which yield a certain return, and also improve the value of the pasture by keeping out cold or dry winds and by affording shelter to the cattle. Broad-leaved species may also be lopped for cattle fodder.

The trees are established by planting strong seedlings, which must be effectively protected against the cattle until the crowns have grown beyond their reach. The trees should be placed in lines.

12. *Forestry combined with the Breeding of Deer and Game.*

A forest which is fenced and stocked with deer or game is called a preserve, or deer forest. Both deer and game interfere much as a rule with the production of trees, the latter being frequently the less important consideration.

High forest is usually preferable to coppice, because regeneration recurs only after longer intervals; at the same time coppice woods suit most kinds of game better than high forest. Species which produce food for the deer, as Oak, Chestnut, etc., should be represented in deer forests.

Young growth must be carefully fenced; planting is preferable to sowing, as the object should be to reduce the regeneration period to a minimum.

SECTION II.—SELECTION OF SYSTEM.

It has been shown in the last section, that each sylvicultural system has its special advantages and disadvantages, and that their effects differ principally in respect of the production of wood, the power of resistance against external dangers, and the preservation of the factors of the locality. All these and many other matters must be considered in selecting the system which is best adapted to any special set of conditions. They may be brought under the following headings:—

(1.) Suitability of the system to the selected species.
(2.) The permanent preservation or even improvement of the factors of the locality.
(3.) Protection against external dangers.
(4.) Safety and simplicity of the method of regeneration.
(5.) Quantity and quality of the produce.
(6.) Intensity of management.
(7.) Existence or absence of forest rights.

1. *Suitability of the System to the selected Species.*

This is a consideration of the first importance in all cases where it is desired to grow a particular species. In the first place, coniferous species cannot be treated as coppice woods; while several broad-leaved species, such as Beech and Birch, possess only a moderate reproductive power by shoots. In all such cases only the high forest systems are indicated; Beech and Birch should not at any rate, be grown in pure coppice woods. Again,

light-demanding species with thin crowns are but badly suited for ordinary simple high-forest; they should be raised as standards in coppice with standards, under the two-storied high forest, or with a coppice underwood. Such species are also difficult to raise under shelter-woods. On the other hand, tender shade-bearers like Beech and Silver Fir are better adapted to the shelter-wood systems than to the clear-cutting system. Lastly, whenever a system involves two crops of uneven age on the same area, the overwood must consist of a thin-crowned, that is to say, light-demanding species, and the underwood of a dense-crowned or shade-bearing species.

2. *Preservation of the Factors of the Locality.*

On general economic principles, forests should be worked and managed for a sustained yield, and not for a temporary high return; hence it is necessary to select a system under which the factors of the locality are at least maintained, and if possible improved.

In the case of exceptionally good localities with a rich fresh soil and a favourable state of moisture and temperature of the air, any system can be adopted which answers to the other requirements of the case, but on all localities of only middling quality, and still more so on poor localities, the first consideration must be the preservation of the factors of the locality, or else a steady deterioration will set in, which may end in complete sterility. In such cases clear cuttings must be avoided as much as possible, and every effort be made to keep the area permanently stocked with a crop

of trees, in other words to regenerate under shelter-woods, so as to lead the old crop gradually over into a new crop. Unless this precaution is taken, the degree of moisture in the soil undergoes violent changes, which act most injuriously on production. The system best adapted in such cases is the Shelter-wood Selection System, and next to it Coppice with Standards, the other shelter-wood systems which produce an uneven-aged young wood, and the Shelter-wood Compartment System.

3. *Protection against External Dangers.*

It should be the object of a good management to produce healthy woods which are capable of resisting successfully the dangers to which they are exposed during life. Though species and method of regeneration are of principal importance in this respect, the system is also of some account.

Where the object is to counteract the eroding effects of water running down sloping ground, to prevent the occurrence of landslips, avalanches, or devastation through moving sand, woods of uneven age must be the rule, such as are produced under the Shelter-wood Selection System, the Group System, etc.

Whether uneven-aged woods suffer less from wind, snow and ice than even-aged woods is as yet an open question.

In respect of frost, drought and insects, the Clear-cutting System yields the worst results, the Shelter-wood Compartment System comes next, and then the systems which produce uneven-aged woods, the Shelter-wood Selection System being best of all.

On the whole, localities differ much; some rarely or

never suffer from storms, snow, etc., while others do so every year. Such peculiarities must be taken into account in selecting the system.

4. *Safety and Simplicity of the Method of Regeneration.*

Whether the one or other method of regeneration is the more suitable depends on local conditions. In some cases artificial, in others natural regeneration by seed or by coppice is indicated. More especially the importance of shelter-woods in the case of middling and inferior localities must never be overlooked, as well as in the case of those which are subject to external dangers. Again, in some cases natural regeneration is easy, in others difficult or almost impossible, and a selection must be made accordingly. Another point is, that trees standing in an uneven-aged wood produce, as a rule, more seed than those in an even-aged wood. Finally, the system which acts most favourably in respect of the factors of the locality will also, as a rule, produce the most favourable germinating bed for the falling seed.

5. *Quantity and Quality of Produce.*

Woods yield timber, firewood, and a variety of minor produce. As regards wood, a distinction must be made between timber and firewood. Where only the latter is wanted, that system is preferable which yields the largest volume or greatest weight of produce within a certain space of time. Where the objects of management centre in the production of timber, other considerations prevail. Such production, if the timber is to be of any size, takes long periods of time, and it demands a con-

tinuous energetic action of the locality. More especially a continuously even degree of moisture in the soil has to be aimed at. Next, the proper amount of light must be given to each individual tree, in other words a sufficiently large and well-developed crown. These considerations lead to the following conclusions:—

(*a.*) On fertile soil, with a sufficient degree of moisture, in the case of shade-bearing species, and under moderately high rotations, the even-aged systems yield satisfactory results, and their selection is justified.

(*b.*) On less fertile soils, which necessitate a careful husbanding of the factors of production, in the case of some of the species being light-demanding, or under a high rotation, the systems of uneven-aged woods are desirable.

The former produce principally long and clean timber, the latter greater girth.

In many cases the objects of management favour the production of minor produce, and the system must be selected accordingly. Where tanning bark of Oak is wanted, the system of coppice is in its place. Osier beds require to be planted in cleared land. The growth of field crops also is only practicable under the system of clear-cutting; at the outside, only a few standards may be left on the ground. Where grass and grazing is wanted the woods should be even-aged, or else the cattle will damage the young trees, etc.

6. *Intensity of Management.*

The more valuable the returns of a forest are, the

more intense, or careful and detailed, should be the system of management, and *vice versâ*.

The capital invested in a forest differs considerably under different systems, it being composed of the value of the land plus the value of the growing stock, apart from buildings, etc., which would be required under any system. Hence, high forest requires a much larger capital than coppice, and often yields a smaller interest on the invested capital than the latter.

Artificial regeneration requires a periodical outlay of cash for sowing and planting, while natural regeneration can be effected without such outlay, though it may involve a considerable loss of time.

The transport of the material is considerably cheaper (up to 20 per cent.) in even-aged woods than in uneven-aged woods, because in the former case the operations are more concentrated. The same holds good as regards supervision.

The clear-cutting systems require a greater total of labour, while the shelter-wood systems require better skilled labour.

The uneven-aged systems make much greater demands than the even-aged on the intelligence and industry of the manager, because they require higher skill and more constant supervision. In the former case the executive charges must be smaller than in the latter.

7. *Existence or Absence of Rights.*

In many cases the existence of rights necessitates the selection of a particular system. For instance, where large timber has to be provided to right-holders, the Coppice System would be inadmissible.

8. *Summary.*

Every sylvicultural system has its advantages and disadvantages, and it is necessary to ascertain in every special case whether the balance of the two tends towards the one or other system. *From a sylvicultural point of view*, the first point for consideration is the general suitability of the system, and next the continued preservation and, if possible, improvement of the factors of the locality; financial considerations should only prevail in so far as they do not interfere with the two former considerations.

END OF VOLUME